May 1955

NUCLEONICS

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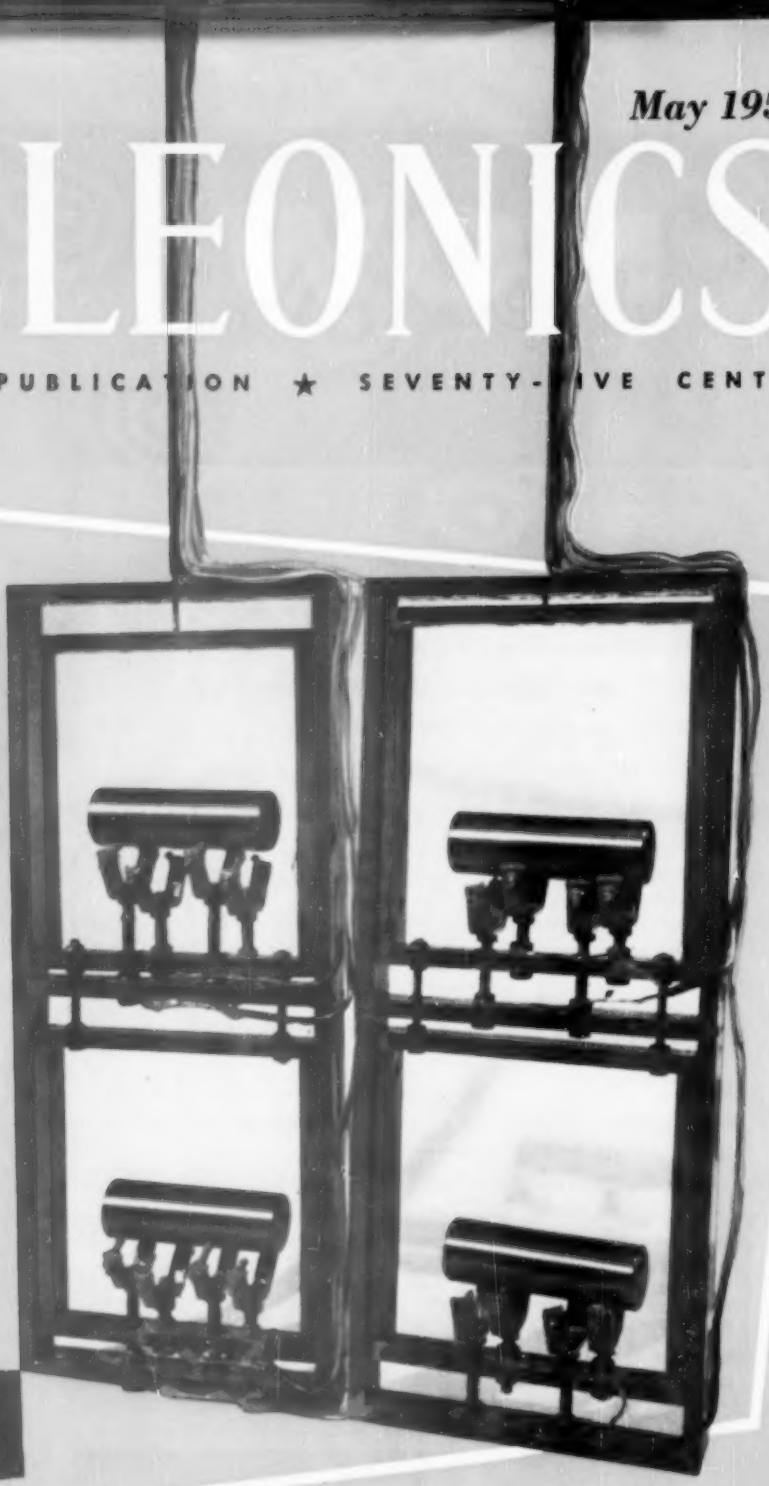

PLATING URANIUM FUEL SLUGS

See page 2

How the U.S. is preparing for the Geneva conference

See page 22

Design for a package power reactor

See page 24

NOW

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IRC *molded* Deposited and Boron Carbon Precistors are now available in 1/8, 1/4 and 1/2 watt sizes. These 1% precision film type resistors combine the advantages of high stability, small size and low cost in either deposited carbon or boron carbon units. Ratings are based on full load at 70°C. ambient.

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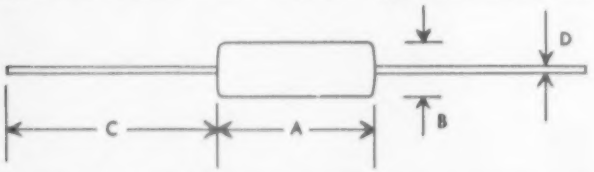
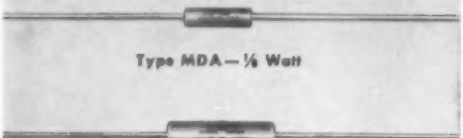
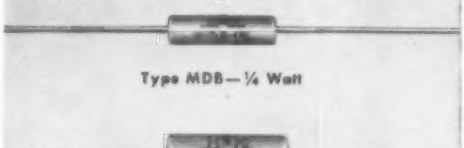


Precistor Types	IRC Size Equivalent	Dimension			
		A	B	C	D
MDA — MBA	BTS	13/32"	1/8"	1½"	.025"
MDB — MBB	BW½	5/8"	3/16"	1½"	.025"
MDC — MBC	BTA	23/32"	1/4"	1½"	.032"

MOLDED DEPOSITED CARBON PRECISTORS



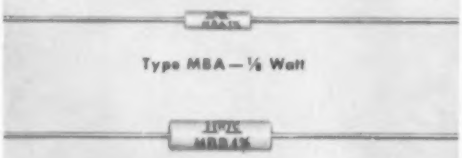
Type MDA — 1/8 Watt



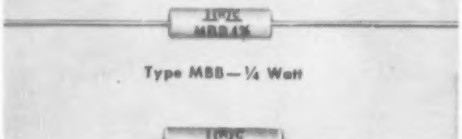
Type MDB — 1/4 Watt

Type MDC — 1/2 Watt

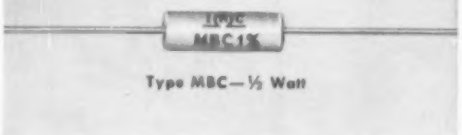
MOLDED BORON CARBON PRECISTORS



Type MBA — 1/8 Watt



Type MBB — 1/4 Watt



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NUCLEONICS

MAY • 1955

Vol. 13, No. 5

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About NUCLEONICS

Why the change in this contents page? It's obvious that what in previous months was a one-page listing of contents is now a two-page listing. Two purposes are served. First, this new format provides space for a more complete listing of what's in each issue. Second, this new column about the magazine has been added.

The editors will use this column to let you know what's coming in later months, what was involved in publishing certain articles in this issue, what's being done to make this magazine even more useful. For example:

Engineering and construction of nuclear power plants. That's the title of a special report being prepared for the June issue—next month. About 40 pages will be crammed with the nuts-and-bolts information engineers need to design and build the nuclear portions of future power plants. Eight sections will cover core construction, reactor vessels, fuel-handling equipment, shielding, leak tightness and testing, water supplies, control mechanisms, and plant layout and site selection.

Planning for this section started over eight months ago. Additional data, requested by NUCLEONICS editors, was flowing in from authors at Argonne, Oak Ridge, Hanford, KAPL, Vitro Corp., North American, American Machine and Foundry, Babcock and Wilcox, and General Electric until just a few weeks ago. The transition from manuscripts to magazine pages is almost complete, and the June issue will reach you on schedule.

Guidance for editors. What is an editor? As we see it, editors exist solely to serve readers. Part of the job is digging up information, the rest serving it as a palatable dish.

Underlying these functions is the requirement of knowing what's good cooking. That's why NUCLEONICS and McGraw-Hill consider studies of

NUCLEONICS

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About NUCLEONICS (Continued)

what, why, and how readers read important. Personal interviews and mail surveys go on continuously. And NUCLEONICS editors are prone to respond to compliments with "What *don't* you like?"

Right now, NUCLEONICS is using a mailed questionnaire to ask a fair sample of its subscribers what they think of two new features: Data Sheets and "Products and Materials" surveys. In this issue there's a data sheet on page 50, a product survey on page 84.

Both these features were started on the basis of putting information into the most usable form. Now we're double-checking that our analysis of what is needed is right.

Sampling methods don't reach every subscriber. Your comments on these two new features and suggestions for future material would be appreciated.

Meetings, meetings everywhere. Every place NUCLEONICS editors go, they find that preparing papers for presentation at meetings has become a major effort. This year of 1955 may well be remembered as the year of nuclear congregation. There's the first meeting of the American Nuclear Society (see Roundup), the nuclear congress arranged by Engineers' Joint Council (NU, Feb. '55, p. 11), the Atomic Industrial Forum annual fall meeting in Washington. Overshadowing all these is the United Nations international conference on peaceful uses of atomic energy in Geneva this August. For sheer bulk of effort and number of papers, it can't be beaten.

Just how extensive United States preparations for this conference are is told in the article starting on page 22 of this issue. We spent a day in Washington last month with George Weil and his staff to get the material for this article.

Next month, we'll report on what's happening at the United Nations, how the UN staff is making arrangements for the conference, what you can expect at Geneva. And we'll keep you posted on current developments in both U. S. and foreign preparations for the conference.

THE COVER

Uranium slugs placed on typical rack ready for plating are shown on this month's cover. This is one of several techniques used to protect slugs from corrosion by coolant that will surround fuel elements in a nuclear reactor. Photo is from Sylvania Electric Products Co.

Introducing AMF's Unitized Research Reactor

A complete unit "ready-made" for universities, research institutes and industry

The unique Unitized Design Concept imparts to AMF Research Reactors extreme flexibility of use, low maintenance cost, minimum expense due to obsolescence and maximum safety. In addition, this highly efficient Facility is as ideally suited for training as for research.

A Unitized Research Reactor is now being built by AMF for Battelle Memorial Institute of Columbus, Ohio. This historic event portends a long step forward in nuclear research. Here is a major contribution to "Atoms For Peace," a force for the betterment of all mankind.

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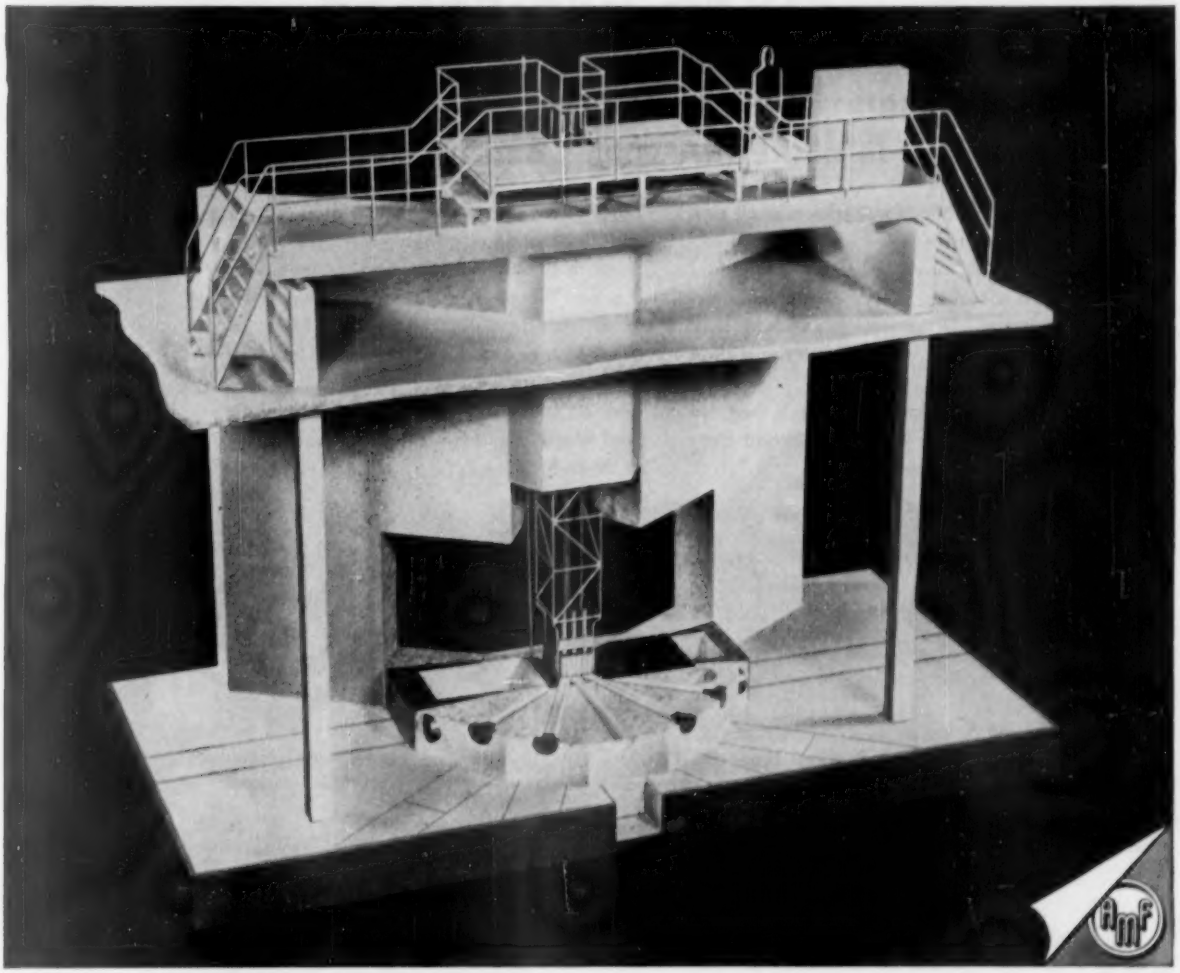
Scale Model of AMF's Unitized Research Reactor (pool and rear shielding cut away)



Core and shielding in this AMF Research Reactor are similar to designs developed in AEC laboratories.

Type TR "tiny" resistors shown in natural size—One unit is magnified to show color-code bands

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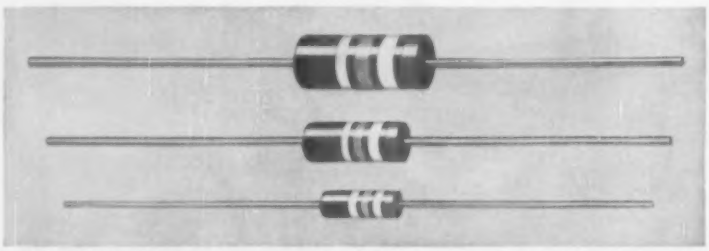

Allen-Bradley Types HB (2-watt), GB (1-watt), and EB (½-watt) solid molded fixed resistors are shown actual size in the above illustration.

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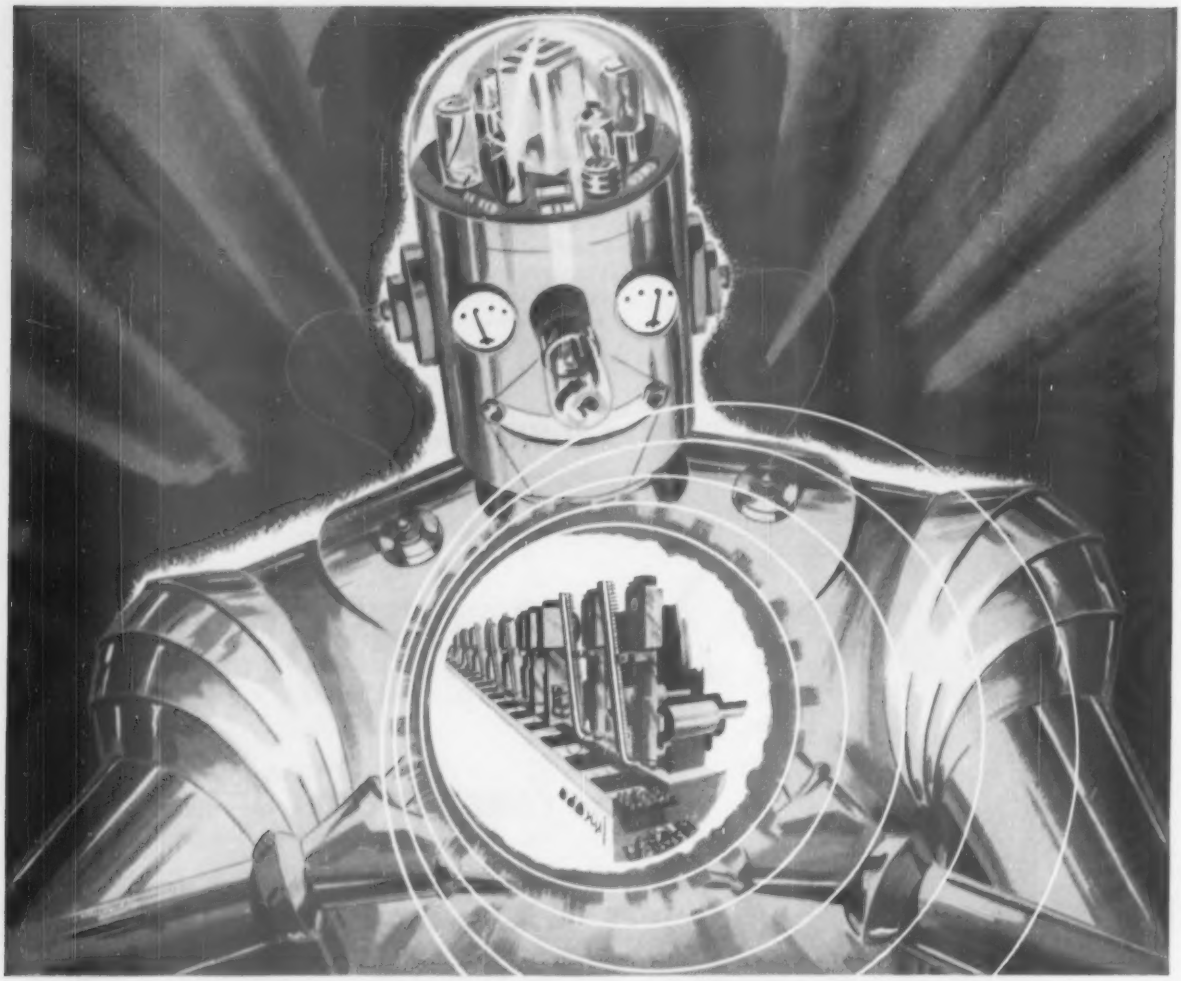

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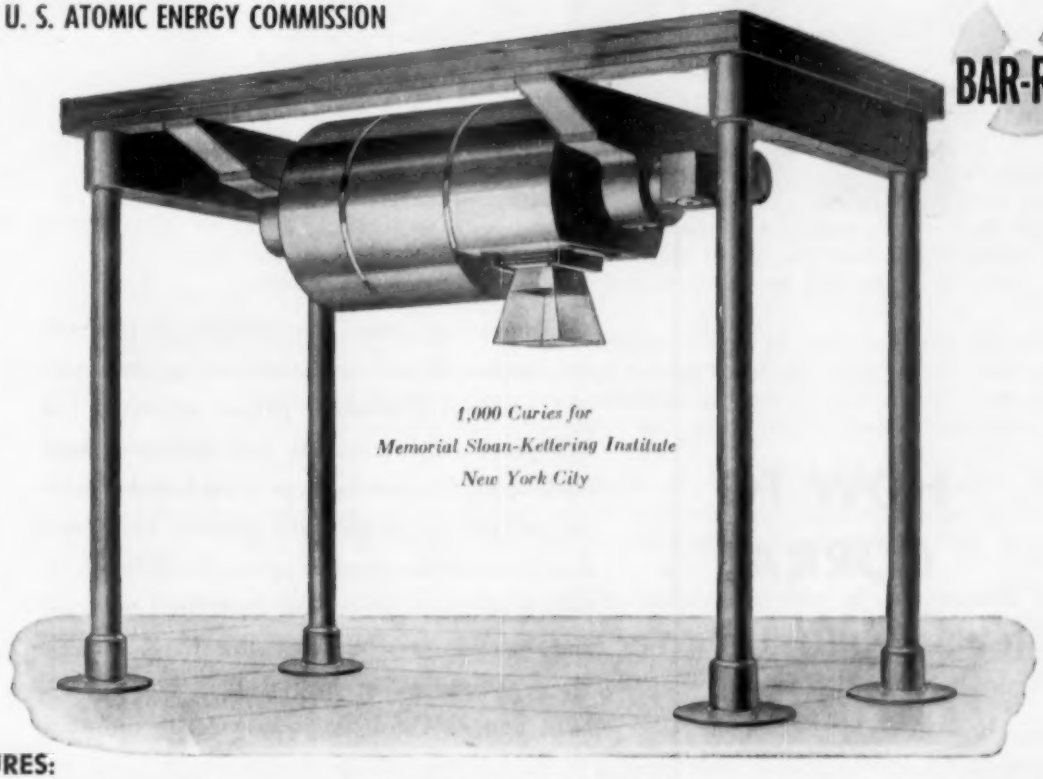

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ROUNDUP of Key Developments in Atomic Energy

LATE NEWS and Commentary

Will Build Nuclear Ship

President Eisenhower has added a nuclear-powered merchant ship to the United States atoms-for-peace program. The ship will carry exhibits of other uses of atomic energy on a world tour.

Immediate support of the plan was given by Congressional leaders. But launching of the ship isn't expected before 1957.

Naval design studies of nuclear-powered surface vessels have been underway at Newport News Shipbuilding and Drydock and at Bethlehem Steel. Westinghouse has been designing a naval ship reactor.

Commercial practicability doesn't enter into the Eisenhower announcement. Westinghouse engineers told an ASME meeting last month that nuclear power couldn't compete at present with conventional maritime plants. And Moore-McCormack, announcing two new luxury liners, said that nuclear power was rejected after considerable study, but predicted economic use in 15 years.

•

Lower Price on Research Isotopes

After July 1, AEC will provide radioisotopes for all biomedical and agricultural research and for research in medical therapy at 20% of catalog prices. Reduction, limited to domestic users, is an extension of price advantage that's been given to cancer research, it won't apply to isotopes for routine clinical treatment.

•

Unattended Reactors

The Army is pushing ahead rapidly on its plans for small power reactors. Four companies (or groups) are scheduled to complete design studies by June 1 for the Army on "unattended operation" reactors (see NU, April '55, p. 11).

•

Uranium Availability

Natural uranium probably will be readily available on a commercial basis throughout the world in three years, according to Gunnar Randers, Director of Joint Dutch-Norwegian Establishment for Nuclear Energy Research. Enriched uranium will also not be very difficult to obtain shortly, he feels, at least for experimental purposes.

In a talk at the California nuclear conference, Randers also said that Norway is actively studying the use of a heavy-water boiling reactor for its planned central-station plant.

•

West Coast Test Reactor

Stanford Research Institute, Stanford, California, is exploring industrial interest in a test reactor that might be built cooperatively in California. Studies for SRI by three companies show "encouragingly moderate cost for 10,000-kw reactor with a flux comparable with that of AEC's MTR."

•

Army to Study Food Feasibility

Before June 30, Quartermaster Food and Container Institute will contract for a one-year feasibility study of logistics and economics of irradiated food. A number of companies have submitted bids.

FCI is sponsoring sessions on its radiation-processing program at two meetings in June. Quartermaster Research and Development Associates session will be on June 10 in Chicago; Institute of Food Technologists session sponsored by FCI will be June 15 in Columbus, O. Write Col. J. D. Peterman, Quartermaster Food and Container Institute, 1819 West Pershing Road, Chicago 9, Ill., to attend.

•

Los Alamos Power Reactor

A new and significant entry into the power reactor business is Los Alamos Scientific Laboratory. AEC's major weapons research center, Los Alamos has a homogeneous power reactor experiment under construction and has plans for expanded nonmilitary reactor activities.

Secrets Unwanted It is reported that one country interested in developing an atomic energy program has turned down a preliminary U. S. offer of enriched uranium because key individuals in the country do not want to get involved in secret agreements with the U. S.

•

Doubts H-Power In the only known statement where an authority with atomic energy project information has permitted himself to be quoted on use of controlled thermonuclear reactions for producing industrial power, J. Robert Oppenheimer, former chairman of AEC's General Advisory Committee, said, "I think they are wrong [optimists on the feasibility of the work]. I don't believe it will work."

It is reported that AEC's very secret work in this area is still a priority effort in a special project at Princeton and the Livermore laboratory. It's also speculated that AEC's fiscal '56 budget request includes an increase in funds for this work.

It's interesting that what some consider a vital development in peaceful atomic energy is missing from the agenda for the UN Geneva conference. However, the first public symposium on the subject will be held at the National Industrial Conference Board meeting in New York in October.

•

Megacurie Sources A proposal that AEC permit production of megacurie cobalt-60 sources in the Hanford or Savannah River production reactors was made at the University of California nuclear engineering conference last month by Bernard Manowitz of Brookhaven National Laboratory. Equating 1×10^6 curies of Co-60 on a neutron absorption basis (use of reactor neutrons) with 3 kilograms of uranium-235, he said that making such production-reactor space available to U. S. industry would have "a very small effect on the weapons program."

To get millions of curies, a source would contain 100 to 1,000 rods 1 inch in diameter by 1 foot. One megacurie operating at 10% efficiency could irradiate 66 tons of materials per hour at a dose of 10,000 r or 0.6 tons per hour to get 1×10^6 r.

Total facility cost for a megacurie source is estimated as—source: $100,000 for irradiation (assuming $35 per gram for U-235), and $50,000 for fabricating 500 rods, or a total of $150,000; transportation of source: $20,000, based on 1 cent per pound per 1,000 miles; building: $500,000. Total operating costs are estimated as $100,000 per year.

•

Offers "Low-Cost" Power Reactor Power at 6 to 9 mills/kwh, from a $21-million, 100,000-kw power plant using an aqueous homogeneous breeder reactor—that's what Foster Wheeler Corp. has said it can complete by 1960–1961 for the utility industry. Costs are within range of those encountered now with conventional plants. Design follows that of smaller units tested at Oak Ridge National Laboratory.

Fuel solution of uranyl sulphate would be pumped outside reactor core to four steam generators producing 600-psi saturated steam. Surrounding core would be spherical blanket of thorium-232; unranium-233 converted from it would be used to refuel reactor. Two heat exchangers would extract heat from breeder blanket to add about 17% to power output. Fuel would be continuously reprocessed, but breeder blanket would be removed for reprocessing periodically.

•

First Atom Pact On May 3, Turkey and the United States signed the first international agreement for exchange of atomic information under the Atomic Energy Act of 1954. Turkey will lease up to six kilograms of enriched uranium for a research reactor, will get unclassified information on reactors and isotope uses.

Adding these Four Power-Demonstration Proposals . . .

Reactor	Operation date	Power (Mw) (heat)	(elec.)	Type	Cost* ($10⁶)	Owner	Probable designer or builder	Location
Nuclear Power Group†	'60	670	180	Boiling water	?	NPG†	General Electric	Chicago, Ill.
Atomic Power Dev. Associates‡	'58	?	100	Fast breeder	45	APDA	APDA	Michigan
Yankee Atomic Electric Co.§	'57	?	100	Press. water	20–25	YAE§	Monsanto + Fluor	Rowe, Mass.
Consumers Public Power Dist. of Columbus	'59	?	75	Sodium graphite	?	CPPDC	North American	Nebraska

To these Eight Already Planned Power¶ Units . . .

Pressurized Water (PWR)	'57	264	≥60	Press. water	85	AEC	Westinghouse	Shippingport, Pa.
Experimental Breeder (EBR-2)	'59	62.5	15	Fast breeder	40	AEC	ANL	NRTS, Idaho
Homogeneous Exp. (HRE-2)	'56	10	2	Homogeneous	3	AEC	ORNL‖	Oak Ridge
Homo. Thorium (HTR)	'59	65	16	Homogen. thorium	44	AEC	ORNL	Oak Ridge
Sodium Reactor Exp. (SRE)	'56	20	0	Sodium-graphite	10	AEC	North American	Santa Susana, Calif.
Boiling Experimental (BER)	'56	20	5	Boiling water	17	AEC	ANL	Lemont, Ill.
Army Package (APPR)	'58	10	1.7	Press. water	2.2+	AEC	American Loco.	Ft. Belvoir, Va.
Consolidated Edison Co.	'59	500	140‖	Press. water	55	Con Ed	Babcock & Wilcox	Peekskill, N. Y.

And these Much-Needed Radiation-Source Reactors . . .

Westinghouse Test (WTR)	'57	10	0	MTR-type?	6.5		Westinghouse	Blairsville, Pa.
Gamma Corporation	'56?	0.5–1	0	Mod. H_2O boiler	0.75	Gamma	To be on bids	Mansfield, Mass.
American Machine & Foundry**	'56	1	0	Swimming pool	1–1.5	AMF**	AMF	NYC area
Armour Research Foundation	'56	0.05	0	Water boiler	0.5	ARF	North American	Chicago, Ill.
Pennsylvania State Univ.	'55	0.1	0	Swimming pool	0.3+	PSU	PSU	State College, Pa.
Univ. of Michigan	'56	1	0	Swimming pool	1	U. of M.	Babcock & Wilcox	Ann Arbor, Mich.
Massachusetts Inst. of Tech.	'57?	?	0	Sw. pool or CP-5	1–1.5	MIT	To be on bids	Cambridge, Mass.
Livermore Laboratory	'57	1	0	Swimming pool	?	AEC	Proposals due 5/23	Livermore, Calif.
Omega West	?	1–4	0	Swimming pool	?	AEC	LASL‖	Los Alamos
Brookhaven Medical	?	1	0	Modified CP-5	?	AEC	To be on bids	Upton, N. Y.
Oak Ridge Research (ORR)	'57	5–10	0	Mod. sw. pool	2.8	AEC	ORNL	[Oak Ridge,
Engineering Test (ETR)	'57	125?	0	MTR-type	10–15	?	[See page 14	NRTS, Idaho
Battelle Memorial Institute	'56	1	0	Swimming pool	1.5	BMI	AMF	[Columbus, O.
Watertown Arsenal	?	?	0	Swimming pool	?	?	Bendix Aviation	Watertown, Mass.
Naval Research Laboratory	'56	0.1	0	Swimming pool	0.3+	?	To be on bids.	Wash., D. C.

Industry Helps Balance U. S. Reactor Program

Giant steps were taken last month toward economically practical nuclear power as specific plans were announced for using substantial amounts of private funds for reactor development and construction. Besides Con Edison's announcement of definite plans to build a power reactor (NU, April '55, p. 5), four other groups made proposals to build nuclear plants under the Atomic Energy Commission's power demon-

* These figures are not directly comparable; e.g., cost of Con Edison project is total (excluding site), to APDA cost add $9-million for generating portion, PWR cost includes $45-million for research and development. † American Gas & Elec. Serv. Corp., Bechtel Corp., Commonwealth Edison Co., Pacific Gas and Elec. Co., Union Elec. Co. ‡ Proposed by Central Hudson Gas and Elec. Corp., Cincinnati Gas and Elec. Corp., Consumers Power Co., Delaware Power and Light Co., Detroit Edison Co., Long Island Lighting Co., Philadelphia Elec. Co., Rochester Gas and Elec. Corp., Toledo Edison Co.; other members of APDA to join later. § New England Power Co., Connecticut Light and Power Co., Boston Edison Co., Central Maine Power Co., Hartford Elec. Light Co., Connecticut Power Co., Western Massachusetts Elec. Co., Public Service Co. of New Hampshire, Montaup Elec. Co., New Bedford Gas and Edison Light Co., Cambridge Elec. Light Co., Central Vermont Public Serv. Corp. ¶ Propulsion reactors not included. ‖ Oil-fired superheater to add another 96 Mw. ** Plus about eight unannounced firms.

stration reactor program. Plans for two more privately financed reactors to be used as radiation sources also were announced.

Working toward goal. Together with AEC's five-year reactor development program and other industry and government reactor plans, some of which are shown in the table above, these projects indicate vigorous U. S. efforts to develop a competitive reactor business that will insure steady development of economically fruitful reactor systems. Last month, W. Kenneth Davis, AEC's director of reactor development, estimated that with an investment of nearly $20-billion by 1977, nuclear reactors in the United States will be capable of generating 100,000 Mw of electricity—about as much as our present capability with conventional plants. He also estimated that in 1965 the U. S. will have 2.5–3 times as much nuclear power as the 1,500–2,000 Mw Britain will have as a result of its recently announced nuclear power program (NU, April '55, p. 9).

Four new power reactors. The four proposals, under which the groups would bear probably 80–90% of the $150-million cost, were made by: Nuclear Power Group; Yankee Atomic Electric Co.: Consumers Public Power District of Columbus, Nebraska; and nine utility members of Atomic Power Development Associates. Other members of the latter group are expected to come in when their directors and state regulatory bodies approve the plan.

Each of the four proposals is intended to come under the Commission's power demonstration reactor program (NU, Feb. '55, p. 5).

Washington Report

The Atomic Energy Commission published three of its five proposed regulations in the Federal Register on April 15: licensing of production and utilization facilities, special nuclear material, and safeguarding of restricted data. Selected industrial groups had reviewed the proposed facilities and special materials sections before publication (NU, April '55, p. 22); these groups had also reviewed operator's license regulations, but these weren't included in the first group published. Also missing were the sections on rules of practice, health and safety, source materials, and byproducts.

Security regulations extend AEC practices to licensees and others possessing classified material. Included are provisions for safes, guard services, and procedures for handling classified material.

Key changes from the special materials regulations as first drafted (NU, April '55, p. 22) are aimed at freeing fuel fabricators and other licensees from red tape in transferring fuel. Thus material transferred from one licensee to another for processing or fabrication is charged to the first licensee and the processor doesn't need a license for each shipment he receives. But responsibility for the material can be transferred with AEC consent.

The major changes in facilities regulations are: individual applications for AEC consent to mortgages, liens or other pledges will not be needed; reports of background radiation and tabulations of reactor controls are not specifically required in license applications.

All license applications are open to public inspection.

Other changes from the drafts are primarily rearrangements and rewording that don't affect intent significantly.

The regulations apply only to complete facilities and not to component parts. Existing AEC regulations governing components will be eliminated, as will AEC licensing controls on export of component parts. But complete facilities built for export still will have to be licensed.

AEC approval is required, even if licensing isn't involved, for direct or indirect participation in production of special nuclear material in a foreign country. Right now each case is considered separately, but AEC hopes eventually to set down some general rules.

Brig. Gen. Kenneth E. Fields succeeded K. D. Nichols as AEC General Manager on May 1. He's been AEC's director of military applications since 1951, was assistant director from 1947 to 1949. From 1945 to 1947, he was assistant to Maj. Gen. Groves, head of the Manhattan Engineer District.

Besides long familiarity with the weapons program, Fields brings other important attributes to the job. Those who've worked with him call him "able," "forthright," "fair, not arbitrary or rash." His reputation includes having a head for details—aides find him up-to-date with all phases of projects that are his responsibility. AEC chairman Strauss is said to have the utmost confidence in him.

Born in 1909, Fields attended the University of Illinois, graduated from West Point in 1933, has masters degrees from MIT and Harvard's Graduate School of Engineering. Before World War II, he served with Corps of Engineers flood and waterway projects. Between AEC stints, he was on the National War College faculty and with the Military Defense Assistance Program in Iran.

Since it would be accelerating civilian nuclear power, the program would get at least part of the $75-million for which AEC has requested obligational authority in its supplementary budget for fiscal '56. Indications are that all four plans could be supported with this amount. After AEC decides which proposals it wants to accept, Congress will have to vote on the appropriation.

Evaluation. The Commission is considering the proposals on bases of: (a) contribution toward achieving competitive power; (b) cost to AEC; (c) risk assumed by proposer; (d) competence of proposer; (e) assurance of completion of project. AEC's evaluation, which is expected to take about another month, is being made by: John Flaherty, manager of the Chicago operations office; Don Burroughs, AEC's comptroller; and U. S. Stabler, John Robinson, and Charles Manly of the reactor development division.

Possible stumbling block. The problem of getting adequate public liability and property damage insurance at reasonable rates from private underwriters could cause a snag in the program; each group's proposal is contingent on getting such coverage. If a reactor safety study now being made by insurance authorities doesn't break the logjam, Federal reinsurance may be needed —and this would mean amending the Atomic Energy Act of 1954.

Radiation-source reactors. Westinghouse Electric Corp. will spend $6.5 million to build a nuclear materials test reactor as the first element of a reactor center on a 550-acre site near Blairsville, Pa. To develop 10 Mw of heat, the highly

KENNETH E. FIELDS is new AEC General Manager. See "Washington Report"

About the Industry

Now you can get AEC classified information with far less restriction on your rights to patent developments based on it. In addition, with confidential data, you won't have to agree to clear public statements with AEC, and reporting of use to AEC will be minimized.

AEC has scrapped the access, study and commercial agreements (NU, Feb. '55, p. 6) of its provisional industrial participation program and replaced them with two sets of conditions for access—one for confidential, the other for secret information.

Confidential data will be made available to any person who can evidence a potential use or application of it in his business, profession or trade. He has to get "L"-clearance and agree in writing to conform to security regulations.

The old access agreements contained a patent clause restricting rights (NU, April '55, p. 25); the new ones probably won't. Instead, AEC says "the Government will waive all rights in inventions and discoveries arising out of access to such information. Where an invention or discovery is made or conceived as the result of access under this program the applicant will waive potential claims against the Government arising from the imposition of secrecy orders on patent applications and for awards under the Atomic Energy Act of 1954."

To get "limited" access to "certain specific" secret data, you will have to show AEC that the data has an immediate and significant effect on your business, profession or trade. A full "Q"-clearance will be needed, and the Government will retain "royalty-free, nonexclusive rights for governmental purposes in inventions and discoveries."

You will have to reimburse AEC for identifiable costs connected with access, including the costs of security clearances in excess of a "certain minimum number"—probably 15 to 25.

Existing study agreements will be converted to the newer arrangements. AEC contractors will get access for private purposes on the same basis and with the same rights as other applicants.

The philosophy underlying General Dynamics Corp.'s increasing emphasis on basic research was spelled out recently by GD's president, John Jay Hopkins. He suggests that nuclear industrialists are largely failing to encourage "a new generation of scientific explorers," warned that in the U. S. "preoccupation with mass production to the virtual exclusion of fundamental design concepts may already have led us into very great peril."

GD is hitting at both points. It established a $4,000 nuclear engineering fellowship (plus one in electronics) last month at Massachusetts Institute of Technology, also gave MIT $5,000 for new laboratories. Case Institute got a similar fellowship last year.

GD's Convair Division is the center of new company emphasis on basic research. After appointing Frederick de Hoffman as assistant vice president for nuclear planning (NU, April '55, p. 82), Convair named a 14-man high-level scientific consulting board and a new director of scientific research, Charles L. Critchfield, physicist from the U. of Minnesota.

enriched water-moderated and -cooled reactor is expected to have greater experimental capacity and flexibility than any reactor yet built in the U. S. Test thimbles into the core will be large enough to test large fuel specimens. In addition to the reactor building, there will be a laboratory, general offices, and service facilities.

Construction of a radiation-source reactor planned by Gamma Corp. of Mansfield, Mass. hinges on lining up a number of contingent contracts of $10,000 each for initial irradiations of up to 10,000 lb-hr. Fuel from the water boiler reactor will supply gammas for research and production studies of radiation-induced biological, chemical, and physical processes. To be built on a 200–300 acre site, the reactor will have an irradiation volume of 5,000 ft^3 and will be part of a laboratory and office area of 7,500 ft^2.

American Nuclear Society Programs June Meeting

A five-session technical program has been set up by ANS for its first meeting June 27–29, Pennsylvania State University, University Park, Pa. Chairman of the technical program committee is J. A. Lane, ORNL. Sessions include:

1. Fast reactor technology. W. H. Zinn (ANL) will be chairman; papers include "design and fabrications of electromagnetic pumps for liquid-metal application," R. G. Rhudy, S. A. Shuler (KAPL); "powder metallurgy of uranium," H. H. Hausner (Sylvania); "centrifugal casting of uranium," J. Schumar (ANL); "an estimation of Doppler effect in fast neutron reactors," G. Goertzel (NDA); "pyrometallurgical processing of reactor fuels," L. Burris, Jr. (ANL).

2. Experimental nuclear techniques. A. M. Weinberg (ORNL) will be chairman; papers include "experimental neutron techniques," D. J. Hughes (BNL); "X-ray and neutron diffraction," R. Pepinsky (Penn. State); "fast exponential and critical experiments," H. Paxton (LASL); "dosimetry in radiation protection," G. Failla (Columbia).

3. Radiation effects. C. K. Beck (N. C. State) and K. Kasschau (Alco) will be co-chairmen; papers include "chemical protection of biological materials from radiation effects," A. Hollaender (ORNL); "examples of the use of radioisotopes in pharmaceutical research," J. M. Kelly (Squibb); "chemical effects of radiation," M. Burton (Notre Dame); "accidental radiolytic precipitation in a homogeneous reactor," C. K. Beck; "recent results in the use of ionic components in protecting glasses from the effects of radiation," R. Hensler (Bausch and Lomb);

Reactor News

SRE heat to make electricity. AEC is expected to approve a plan for generation of electricity from the 20 Mw of heat developed by the Sodium Reactor Experiment being built by North American Aviation. Although it was not originally intended to do this, work is already under way and power probably will be sold to a utility in the Los Angeles area.

AEC sets up staff group on reactor safety. To relieve its advisory group of nonadvisory duties, AEC is setting up a small group to perform staff evaluation of reactor safety. To be headed by Henry T. Wensel, now responsible to deputy manager A. Tammaro, the group later may be under the new licensing division.

Some safety advisors believe new reactor ideas first should be tested in remote areas. There is some feeling on AEC's Advisory Committee on Reactor Safeguards that no reactor that uses any new, untried systems or parts of systems should be built in populated areas. This school of thought feels new ideas should be tried out in remote areas in prototype reactors and that containment methods are untested. If this view prevails, some of the proposed industrial power reactors may run into difficulties.

Commission moves on ETR. Its immediate need for a high-flux irradiation facility (NU, April, '55, p. 11) caused AEC on April 15th to telegraph invitations to a number of companies to submit architect-engineering design proposals for an engineering test reactor facility (including core) by April 26th. Firm picked will be asked to finish design within one year so that a builder can start construction in Idaho in October '55 and the reactor can operate in March '57. Meanwhile AEC continues to try to interest a company in taking over entire project with its own funds; but if no such firm is found by July 1, Commission will go ahead itself. AEC would contract with a private owner for "a substantial amount" of the irradiation capacity for the first 5 years.

Annual operating costs, not including experiment costs, estimated at $4–5-million would cover fuel fabrication, burnup, recovery of U^{235}, 20-yr amortization, and 15% overhead. Core should be flexible to provide for insertion of 15-in.-diameter specimens. At least eleven holes ranging from 3 to 9 in. square are suggested; uniform average fluxes of 4×10^{14} n/cm^2/sec are to be provided over 24–36-in. hole lengths with 10^{15} at the midplane.

French G-1 and G-2 reactors to produce 62–65 kg of Pu/yr. The French G-1, an air-cooled reactor using 1,600 metric tons of graphite and an initial charge of 100 tons of uranium, will produce 12–15 kg of plutonium per year and 5 Mw of electricity after it gets up to full power in July '56. Although G-2, which will be operating by 1957, will use about the same size initial charge, its pressurized CO_2 coolant will be used to generate enough electricity to meet its needs, make up G-1's deficit, and supply over 15 Mw to Electricite de France's grid while producing about 50 kg of Pu per year.

Rural power needs covered in one of two new studies. National Rural Electric Cooperative Association and the Puget Sound Utilities Council have been approved by AEC for 1-year nuclear power studies. Latter is composed of five utility organizations in the state of Washington.

"radiation effects in metals," D. S. Billington (ORNL).

4. Reactor materials. Papers include "economics of the large-scale isotope enrichment of nitrogen-15," J. S. Drury (ORNL); "recent developments in the technology of ceramic materials for nuclear energy service," J. M. Warde (ORNL); "heavy-water production," P. Harteck (RPI); "beryllium materials and compounds for high-temperature application," W. W. Beaver (Brush Be Co.); "mechanism of dimensional instability in uranium," L. Seigle (Sylvania).

5. Nuclear chemical problems. S. Lawroski (ANL) is chairman; papers include "operating experience with a small versatile radiochemical processing plant," H. K. Jackson, G. S. Sadowski (ORNL); "chemical processing of liquid metal fuels," R. H. Wiswall (BNL); "the impact of waste disposal on chemical processing," C. P. Straub (ORNL); "fission-product buildup and distribution in long-burning thermal reactors," W. L. Robb (KAPL); "relative biological hazards associated with nuclear reactors," E. D. Arnold, A. T. Gresky (ORNL).

Albert Einstein Dies at 76 in Princeton

Death came to Albert Einstein at 1:15 a.m. on April 18. He had been a patient at Princeton Hospital for three days. Left lying on the cluttered desk in his Institute for Advanced Study office were his last notes on the unified field theory that had occupied his recent years.

The noted scientist considered this theory the culmination of fifty years of research in the field of relativity. A byproduct of this research —the principle of equivalence of mass and energy—is one of the cornerstones of nuclear science.

Einstein can also be credited with triggering the present United States atomic energy program; it was a letter from him to President Roosevelt that led to setting up of the wartime atomic project.

Einstein's research was not confined to relativity. His early work on the photoelectric effect won him the Nobel prize. In one of the many tributes paid upon his death, Max Born said, "He would have been one of the greatest theoretical physicists of all time even if he had not written a single line on relativity."

Industrial Applications

Portable crop irradiator designed; charge 1¢ per bushel, make profit at $1 per curie. Conceptual designs for portable crop irradiators were recently presented by W. E. Chamberlain, American Machine and Foundry Co. Grain units would be railroad-car mounted, irradiate incoming grain at terminal elevators to 10,000 rep, to kill or sterilize insects. Potato irradiators would be trailer-truck mounted, and provide the same dose to lengthen storage life. Cost figures show that potential profit increases as source size (and crop through-put rate) increases. Thus, figuring irradiation charges of 1¢/bushel, break-even point for 200-kc source is price of $1/c (for a 1-Mev gamma particle per disintegration). For 100-kc source, break-even point is 50¢/c. Gross profit from a 1,000 kc irradiator would be $150,000 if source price were $1/c. One estimate for large cesium-137 sources was 32¢/c (NU, Sept., '54, p. 69).

Radiation-sterilized pharmaceuticals in production. Production-line use of radiation sterilization for drugs is a reality at the Bradley Container Corp. Presumably, the drugs are being stored awaiting FDA marketing approval. Empty polyethylene containers are also being sterilized for drug makers, using the same 2-Mev Van de Graaff. Sizes to 1 fluid oz can be handled.

Free electron-irradiation offered. To explore the feasibility of radiation processing, industry has been offered free use of electron-irradiation services by the General Electric Co. X-ray department, Milwaukee, Wis. G. E. is developing a 4-Mev resonant transformer. A new 2-Mev and a 1-Mev unit are being sold, as well as rented, to users. Output of the 1-Mev unit has been raised to 7×10^7 rep/min.

Argon-41 (109-min half-life) used as tracer. Because of its chemical inertness, low health hazard, and ease of use, argon-41 was used as a gaseous tracer, to check on leaks in an underground gas-storage field 60-miles south of Chicago. In these storage fields 1,750-ft wells are drilled down to a porous formation sealed on top and bottom by impervious minerals. When leaks occured, the well-casing tightness was questioned. To determine possible leakage, argon was injected at bottom of well, and a detector lowered to monitor any gas flow up the casing. In making 27 tests, over 40 c of argon-41 was handled, with field exposures of less than 10 mr per test.

The rigid timetable followed was: 8 a.m.-discharge argon after 12–16-hr overnight production run in Argonne's CP-5 reactor, 10 a.m.-transfer to injection tank at field after car-transit from reactor, 11 a.m.-injector in position, 12 p.m.-detector ready, 12:30 p.m.-release tracer, 5:30 p.m.-test conclusion. Initial activity produced for each test was about 1,470 mc, at test's end about 43 mc remained. Tracerlab, Inc. personnel who conducted these tests found argon superior to the 35-hr bromine-82 that was the next alternative.

ROUNDUP

News in Brief

U. S. circulates draft constitution for international agency. If replies from Britain, France, Canada, Australia, Belgium, Portugal, and South Africa—proposed charter members—are favorable, Congress may be asked this summer to ratify necessary agreements to set up the agency. Most important question still unsettled is whether each nation will have one vote in agency, or whether voting power will vary according to nuclear development. Relation of agency to UN would be determined after it is set up. Soviet Union, invited to participate, has not yet replied.

National Academy of Sciences will study biological effects of radiation. Rockefeller Foundation funds and AEC cooperation have been pledged to a broad appraisal of present knowledge. Academy will appoint a scientific committee to collect and judge data, identify problems, and initiate further research.

Eisenhower recommends AEC budget cut of $75.9-million. Lower construction costs and other economies will let AEC operate at planned scale in fiscal '56 with $1,045-million instead of $1,121-million originally asked of Congress. Appropriations subcommittee considering budget has not yet scheduled hearings.

Britain building linear accelerator, orders Van de Graaff; Finland gets first accelerator. Airfield adjoining Harwell research establishment is the site for 800-ft linear proton accelerator. U. K. Atomic Energy Authority has ordered a 6-Mev machine from High Voltage Engineering, Cambridge, Mass., that will cost $402,700. A 3-Mev positive-ion van de Graaff has been under construction at Helsinki University's physics institute since 1947.

Film badge supply and service discontinued at AEC's Health and Safety Laboratory. Contractors in the northeastern area will have to switch to commercial services. Service by AEC's New York office was started in 1947; almost 300,000 film badges were handled.

Cockcroft will keynote fourth annual NICB meeting on atomic energy in industry. National Industrial Conference Board has chosen international cooperation as the theme for its October 26–28 meeting in New York. Sir John Cockcroft will review international developments. A conducted tour of Brookhaven National Laboratory is planned for October 29.

Secretary of Labor sets up study committee on atomic energy labor-management problems. James P. Mitchell wants a five-man group to advise him on working conditions at atomic installations. Labor department has no statutory responsibility; disputes are settled by Federal Mediation and Conciliation Service. But Mitchell stepped in to help avert major strike last summer.

Westinghouse fellowship program coordinates on-the-job training with nuclear power education. Cooperating with the University of Pittsburgh, Westinghouse will let selected college graduates earn their masters degrees in nuclear power and at the same time get industry-scale salaries. Following initial college-industry phase, graduates will be eligible for paid educational leave to obtain a doctorate. Nuclear engineering courses will be offered by Westinghouse educational department and atomic power division.

Japanese government group will study peaceful uses; Chugoku area engineers ask Yates for details on his Hiroshima reactor proposal. The Ministry of International Trade and Industry has established an atomic energy section in its industry technological institute. A group of engineers in the Chugoku area that includes Hiroshima, wrote to Rep. Sidney R. Yates (D., Ill.) for economic data on the nuclear power plant he proposed be built in Japan, and for comment on how radioactivity discharged from the plant could be dealt with (NU, Mar. '55, p. 8). They pointed out that Japanese have raised two objections to the proposal—that the relief of A-bomb victims and restoration of bombed cities should take precedence, and that radioactivity from the plant might affect surrounding areas. But the engineers themselves favor the proposal—Chugoku power requirements are increasing 10% annually from the present 500,000 kw, charges are higher than elsewhere in Japan, and coal reserves are adequate for only 10,000 tons/day.

North Carolina State offers one-month course for industrial participation in nuclear power developments. Reactor calculations and design, chemical principles, chemical systems for reactors, safety, metallurgy and reactor materials, nuclear development trends, reactor operation and control—these courses are designed to give engineers background in atomic energy. Deadline for admission to $500 course is June 1. Write A. Menius, Raleigh Research Reactor, N. C. State College, Raleigh.

Potato irradiation will be discussed at Brookhaven meeting May 25. Biological, physical and industrial aspects will be discussed by workers from BNL, Cornell, Michigan, Department of Agriculture, MIT, General Foods, and Army medical nutritions laboratory. To attend, notify A. H. Sparrow, BNL, Upton, N. Y.

AEC issued six interim special nuclear material licenses before regulations were written. U. of Chicago was licensed for 1 gm of uranyl nitrate for fission-product studies; Naval Radiological Defense Laboratory, for 5 gm U-235, 1 gm U-233, 4 gm Pu-239 for same purpose; Columbia U. for 0.1 microcurie Pu-239 for instrument calibration; Carnegie Institute of Washington, for 100 mg U-235 for studies of Coulomb excitation; Army, for depleted MTR fuel elements for use in gamma-ray food irradiation unit. Over 17 queries about licenses and procedures for licensing nuclear facilities were received.

Fermi papers, notes and correspondence given to University of Chicago library. Emilio Segrè will edit a definitive edition of Enrico Fermi's publications based on this gift from Mrs. Laura Fermi. The collection dates from 1938; most of Fermi's earlier working papers are believed to be at the University of Rome. As they are declassified, Manhattan Project and Los Alamos papers and notebooks will be added.

First atoms-for-peace isotopes course starts, 21 countries represented. On May 2, students from Australia, Canada, Chile, Colombia, Cuba, Egypt, Finland, Germany, Greece, Guatemala, India, Italy, Japan, Mexico, The Netherlands, Pakistan, Peru, Philippines, Spain, Thailand, and Venezuela started the Oak Ridge Institute of Nuclear Studies course (NU, Jan. '55, p. 79). Fall repeat session is being scheduled for overflow of applicants.

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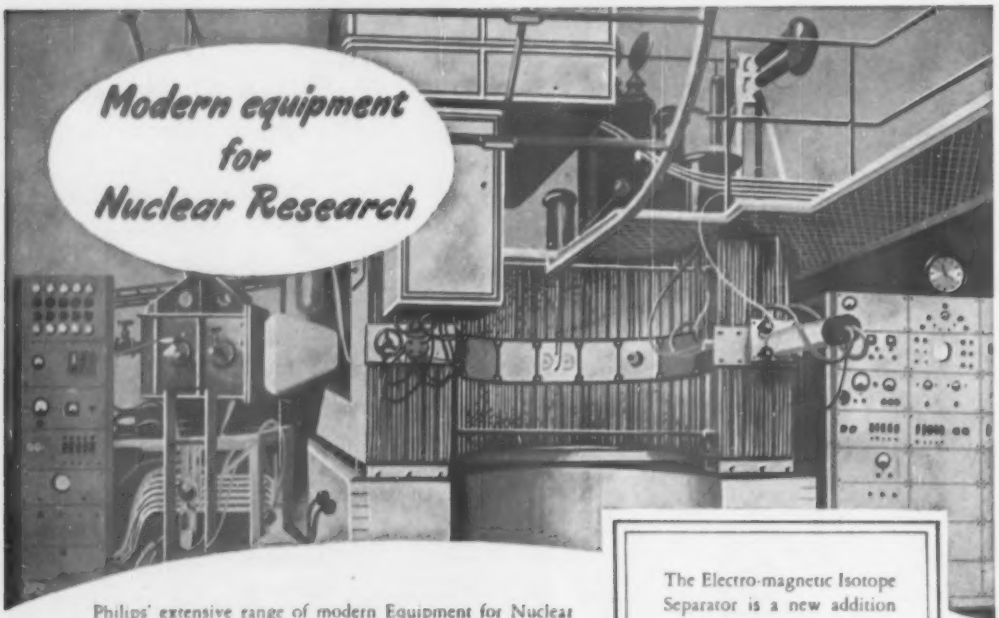

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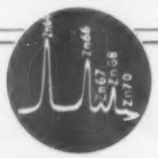

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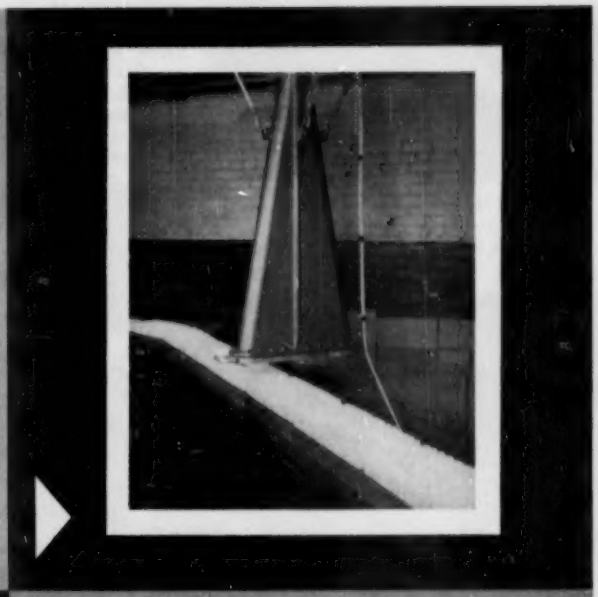

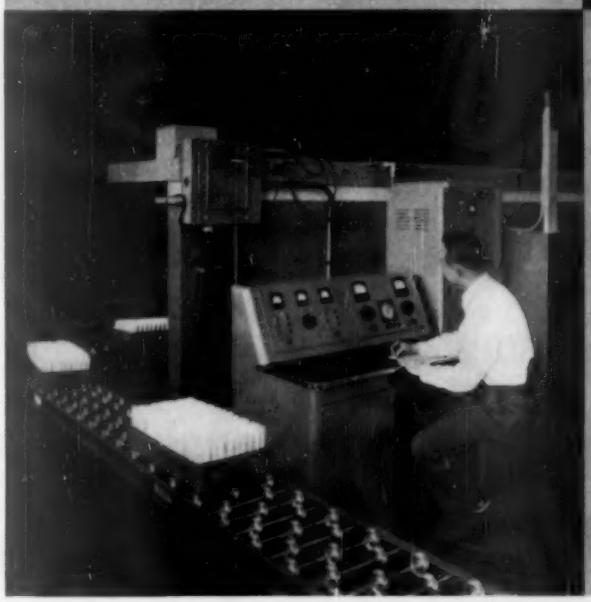

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NUCLEONICS MAY, 1955

Jerome D. Luntz, *Editor*

An Industry Takes Shape

WITHIN A TWO WEEK PERIOD last month, civilian nuclear power development in the United States took a giant step forward. Four private companies or groups and one public organization announced plans for large power reactors. Another company revealed its intent to build an industrial test reactor. These added to previously announced plans for two other private test reactors, five government power reactors or prototypes, five university research reactors, and three government research reactors make for a very dramatic and impressive U. S. program. (See p. 11 for details.)

Because all of the U. S. plants are scheduled for completion by 1960, it is possible that this sudden spurt of activity will thrust the U. S. ahead of the British, despite the United Kingdom's very bold plans to build 16 power reactors in the next 10 years. Actually, with the secrecy covering both programs, it is impossible to tell who is ahead. Of much greater importance than who is ahead, however, is what will these gigantic efforts bring us.

There is now little doubt but that come 1960 we shall have the answer to the oft-raised questions—"When will we have economic power, and in what parts of the world?" "What reactor types will be the best bets for economic power?"

It is inevitable that we shall have these answers, because although we have had reams of paper studies that have pointed in various directions, we have lacked engineering experience and data. Now, by 1960, we will have data on many types of reactors (fast breeders, light-water-cooled and moderated plants, boiling water reactors, heavy water reactors, etc.), different nuclear fuel types and configurations (U^{235}, U^{233}, Pu^{239}, solid and liquid fuels, long-burnup elements, thorium as fertile material), and various kinds of coolants and moderators (light and heavy water, graphite, gas, liquid metals).

FOR THIS STARTLING, seemingly overnight, turn in events, congratulations are due all around—to Consolidated Edison of New York for planning the first 100% privately owned power reactor; to the four groups that submitted proposals under AEC's power demonstration reactor program; and to Congress for having faith in the sincerity of interest of private industry in going ahead in this business and passing a law to make it possible.

Not to be overlooked in any way is the Atomic Energy Commission's interest in pushing non-government development via its demonstration program. Contrary to Congressional criticism that this program would tend to thwart private initiative, we believe that it actually has served as a spur. At the least, the April 1 deadline for proposals was a pyschological deadline that industry felt it had to meet to show its real interest. No one will know whether if not for this program industry would have anted up money to cover 100% of the cost of such plants. But it doesn't matter because the fact remains that we do now have plans for building under this program.

According to its original plan, AEC will now select those of the present proposals that it considers "best." But we raise the question of whether any of the proposals should be turned down if they meet AEC's license and regulation requirements. Assuming the four proposals meet health and safety standards, we feel the basic questions that have to be answered are: (a) Are there adequate funds available for the four plans? (b) Is there adequate nuclear fuel available?

The answer to both certainly appears to be yes. AEC is asking Congress for $75-million for this program which should be more than enough for this first go-round. And Congress certainly seems to be disposed to foster such activities.

On the question of fuel, AEC experts have repeatedly said that our uranium resources are quite sufficient to support any conceivable civilian effort. In any event, if enough were not now on hand, by the time it were actually needed, a supply could be produced.

LOOKING AHEAD TO THE FUTURE, we anticipate that there is going to be further industrial interest in AEC's demonstration program and that AEC will want to follow through on its plan to accept additional proposals at a later date. It would be desirable for industry to insist on a straight licensing arrangement under which any financial support would be for specific research assistance under Sec. 31a of the law. This would keep informational and patent "involvements" with AEC to a minimum.

Backing up all this direct activity on power reactors are the plans for industry to build test reactors and fuel fabrication facilities, and to study chemical processing of fuels. These are areas in which both AEC and industry should be meeting their needs by buying from industry.

The form of the industrial complex that will comprise the atomic energy industry is indeed beginning to take shape.

He's Directing U.S. Efforts

George Weil, director of AEC Office of International Conference, tells NUCLEONICS—"To present as much useful information as possible, we're pushing three projects simultaneously . . .

"About 400 technical papers are being prepared, including comprehensive reviews . . .

"Two exhibits will emphasize our national contribution, rather than individual products. We will give many their first look at actual operation of a research reactor . . .

How U. S. Is Preparing for UN

THE FIVE-DAY WEEK has been discarded at the Office for International Conference (OIC) where preparations are being made for U. S. participation in the UN meeting on peaceful uses of atomic energy. This group is on a six-day-plus-overtime schedule, with seven days not exceptional.

Primary reason for this hectic atmosphere is that the conference starts August 8 in Geneva, Switzerland. And the United States aims to have the largest block of atomic energy information ever assembled for presentation ready by then. Included are some 400 technical program papers, and two comprehensive exhibits, topped by a working research reactor.

Spearheading this effort as the office's director is George L. Weil. Formerly with AEC, he left to establish his own consulting practice, is now assigned to AEC's General Manager's office for this project. Working with him is a group composed chiefly of AEC personnel on leave from their regular jobs. Paul McDaniel, deputy director, AEC division of research, is coordinating preparation of technical papers. Alberto Thompson, AEC's director of technical information, is handling the exhibits and information package, aided by Richard L. Brecker, on loan from U. S. Information Agency. George Manov, assistant to AEC assistant general manager for research and development, is in charge of the reactor project. T. O. Jones, assistant to the deputy director of AEC's production division, is in charge of all administrative functions.

Weil emphasizes that he and his group can see success in their efforts only because of the extremes of cooperation they're encountering within AEC and with industry and educational institutions. "We haven't worried about protocol," he says, "To do our job, we've had to move ahead rapidly, with many activities in parallel rather than in series and acting intuitively, hoping that the forward component of movement is a large one. We're more than pleased with the cooperation we've been getting."

The U. S. has a unique problem among conference nations. Its extensive atomic effort and growing nuclear industry make it virtually impossible to include all available papers and possible exhibits. The aim is to coordinate the phases of the program outlined at the top of this page so that a comprehensive picture of our national effort can be presented at the conference. Thus speakers will represent the United States and not their individual organizations.

Emphasis is being placed on reactor technology and nuclear power, but isotope applications in industry, science and medicine are far from being neglected. The U. S. wants to present material useful to all nations, no matter what their status in nuclear technology.

"Only extremes in cooperation are making this program possible. Everything has to be, and is, moving forward at once."

sides reviewing submitted abstracts, they have also suggested comprehensive "status reports" to be prepared for the conference.

The idea is that the status reports will be a major share of material presented orally at the conference, giving an over-all view of American work in each field. This will be backed up by more detailed papers, most of them appearing only in the published conference proceedings.

Acting on the review recommendations, OIC on April 8 selected about 450 possible papers. By April 15, it sent out invitations asking authors to prepare papers by May 20. These invitations contained detailed recommendations of what each paper should contain. By July 1, printed copies of the papers will be sent to the UN.

But just what papers will be presented at the conference won't be known much before June 15. The UN advisory committee will make that decision on the basis of abstracts OIC supplies by May 15. It's expected that 150–200 papers will be presented. This would account for about half of the 169-hour conference program.

Exhibits, Reactor

Not knowing what space the UN will finally allot, OIC is planning for a highly technical exhibit in the library wing of the Palais where the conference will be held. In addition, at the downtown exposition hall, the largest of the popular U. S. Information Agency exhibits that have been touring Europe will be augmented by OIC for Geneva showing at the same time as the conference.

About two-thirds of the Palais exhibit will be devoted to reactor technology. The rest of the exhibit will be divided about equally between nuclear instrumentation and isotope applications. In both these categories, the aim is to have as many "working" exhibits as possible. That is, actual operation will be demonstrated, not just depicted.

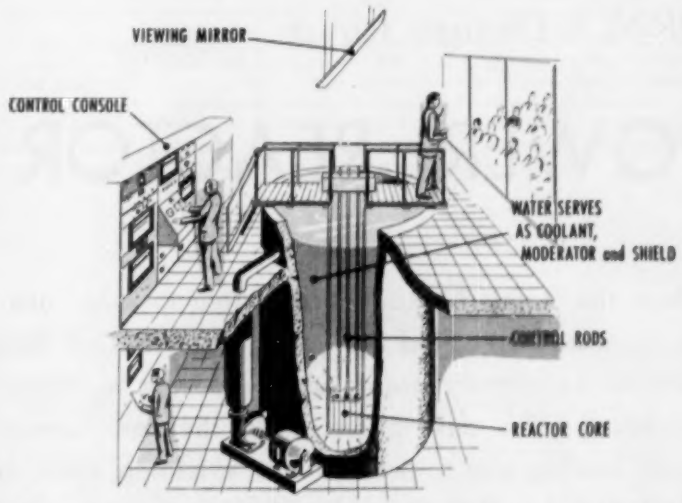
Just outside the Palais, a temporary building will house what may be the highlight of the U. S. exhibit—a working research reactor (NU, April '55, p. 7). The diagram on this page shows how the proposed unit will be set up. —END

Conference

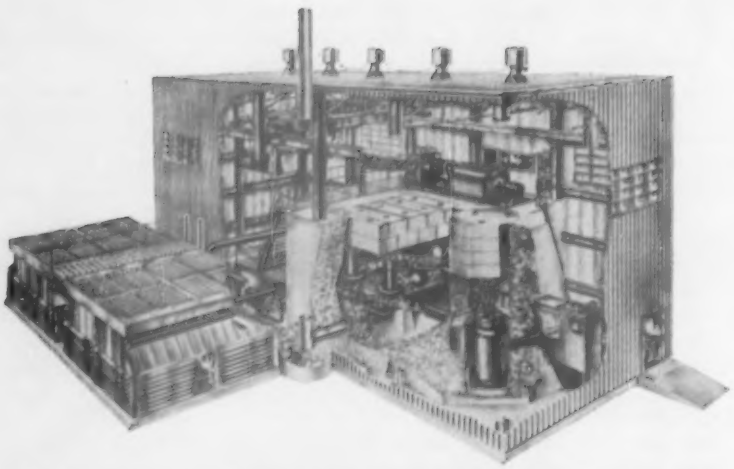
Technical Papers

Consistent with United States aim of providing a wealth of usable information, the method of coordinating papers submitted for the conference is elaborate. Invitations to submit abstracts were sent out by OIC on February 20. Early in April, over 930 abstracts had been received. About 53% came from AEC, its contractors, and other government agencies and contractors. Hospitals, medical schools and research laboratories accounted for about 22%; academic institutions and endowed foundations, 14%. Almost 11% came from industry. Each abstract was acknowledged.

Copies of each abstract went to committees set up especially to recommend what papers should be submitted to the UN. Seven such review committees cover physics, reactors, isotopes, raw materials, biology and medicine (8 independent subcommittees), economics, and metallurgy. Be-



POOL REACTOR will look like this at Geneva. Pouring of concrete started last month. Oak Ridge National Laboratory is fabricating fuel rods, building reactor core and controls. Unit will be tested to full criticality at ORNL, then disassembled, crated, shipped with fresh fuel. Reassembly there will be simplified by this pretesting, plus use of plug-in instruments, controls. For public demonstration and to make possible operating of reactor by conference delegates, added safety features include oversize control rods, duplicate and triplicate instruments. ORNL will send 6 operators, 2 or more health physicists with unit. Handbook of operating techniques, safety, and research capabilities will be available. After conference, and cooling period, reactor fuel will be returned to U. S. in shielded casks



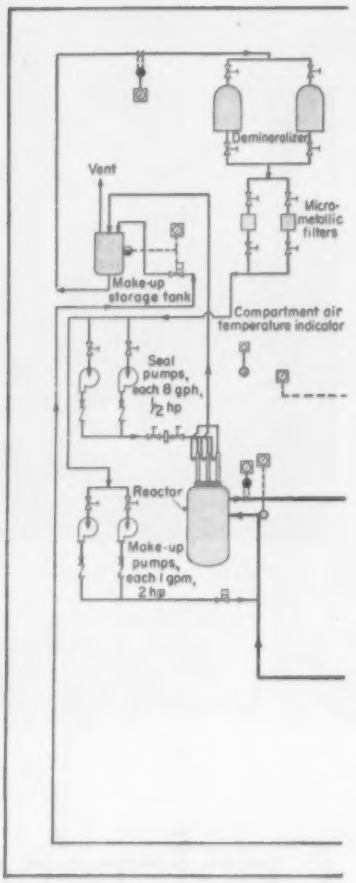


FIG. 1. Package reactor power plant design uses heterogeneous water-cooled and -moderated core of stainless-steel-clad enriched-uranium fuel. Standard components are used wherever possible, and all special items, such as pressure vessel, heat exchangers, and control-rod mechanisms, are designed within present technology. Plant is designed to be built above grade in 3-month period at remote location where water supply is limited to amounts haulable by truck, where all equipment and materials are transportable by airplane (concrete aggregates are available at site), and where air temperature ranges from −50 to +75° F

ORNL's Design for a

POWER REACTOR PACKAGE

Before the Army Package Power Reactor—for use in remote areas—reached the contract stage, Oak Ridge National Laboratory prepared this design to estimate feasibility. This description covers the core, pressure vessel, cooling and control systems, shielding, costs, and calculations for criticality and control

By R. S. LIVINGSTON and A. L. BOCH
*Oak Ridge National Laboratory**
Oak Ridge, Tennessee

DESIGN OF THE REACTOR system concept from which package nuclear power plants are being developed provides understanding of desirable design features and how they are being evolved. The general factors that lead to the forced-circulation water-moderated system include its comparatively advanced stage of component development, reliability, and low initial cost.

The conceptual design described here was made by Oak Ridge National Laboratory as a practical step toward construction of a package nuclear power plant. A full-scale prototype of Ameri-

* Operated by Carbide and Carbon Chemicals Co. for the U. S. Atomic Energy Commission.

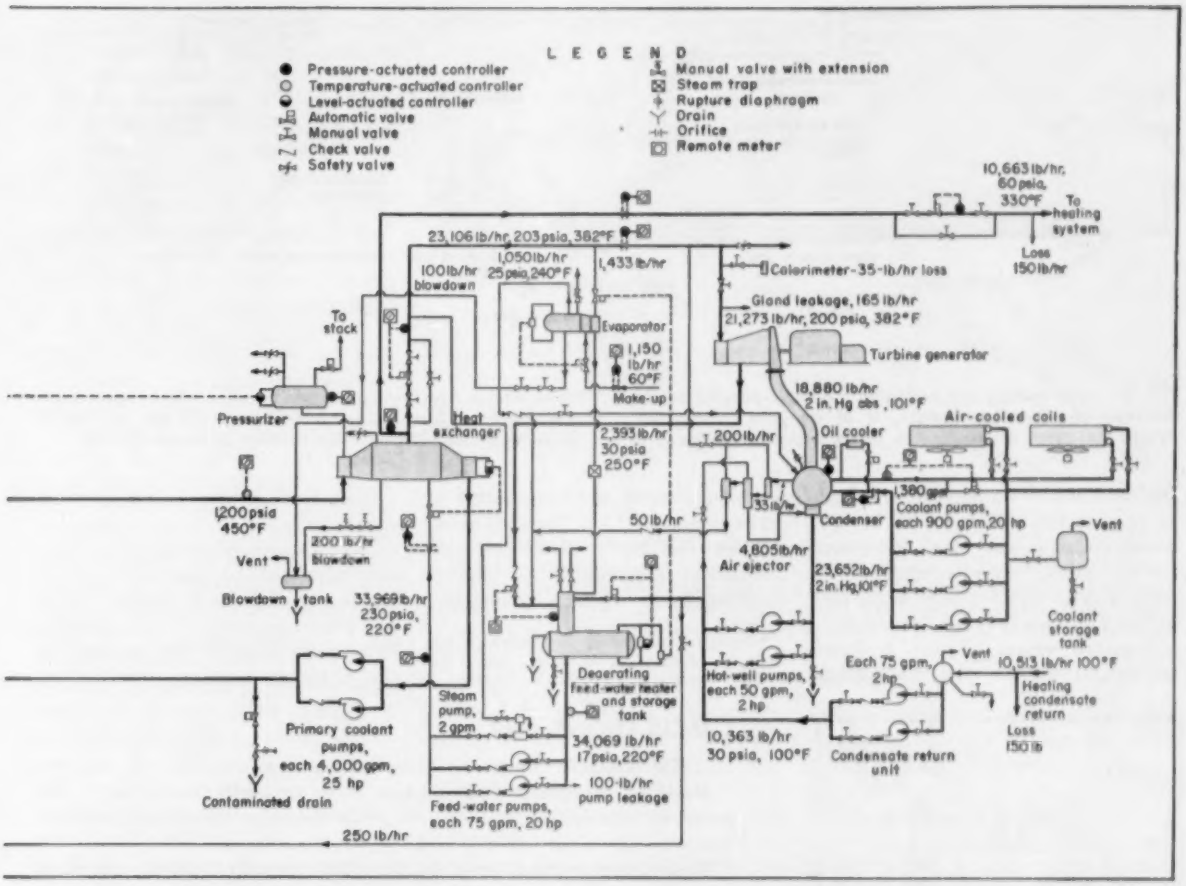


FIG. 2. Water transfers heat from reactor core to main heat exchanger, where heat generates steam to provide space heating and drive a turbogenerator. Continuous bleed and discard of primary coolant maintains low corrosion-product concentration; water from make-up storage tank (which gets condensate periodically from steam cycle) goes through demineralizer and filters and then is injected into primary-coolant cycle by make-up pumps. Electrically heated pressurizer at high point of system maintains pressure at 1,200 psia to prevent boiling in reactor. Raw water to make-up steam cycle is converted to steam in evaporator; deaerator combines this steam with and helps heat feed water before it enters heat exchanger. Steam-jet air injector maintains vacuum in turbine condenser. Air coolers remove heat from main turbine condenser coolant

can Locomotive Company's version of this plant will be built and tested at Fort Belvoir, Virginia, to evaluate the performance of this type of power plant (NU, Jan. '55, p. 76; Oct. '54, p. 22).

The ORNL Design

Although the 10-Mw reactor, shielding, and 1-Mw power generating equipment shown in Figs. 1–5 weigh about 1,300 tons, the components can be airlifted to remote locations and assembled in a short construction season.

Reactor core. Fuel assemblies of highly enriched uranium fuel are clad with stainless steel to protect the uranium from the highly corrosive hot-water coolant. The less than 25 kg of

PLANT PERFORMANCE

Heat developed, kw	*10,000*	*Coolant:*	
Btu/hr	*34.1 × 10⁶*	*Inlet temperature, °F*	*432*
Electric power, kw	*1,300*	*Outlet temperature, °F*	*450*
Power for auxiliaries, kw	*300*	*Density at 450° F, lb/ft³*	*51.75*
Net electricity, kw	*1,000*	*at 432° F, lb/ft³*	*52.60*
Steam heat load delivered, kw	*3,535*	*Change in density, lb/ft³/°F*	*0.046*
Btu/hr	*12.1 × 10⁶*	*Viscosity at 445° F, lb/ft/hr*	*0.295*
Over-all thermal efficiency, %	*45.4*	*Thermal conductivity, Btu/hr/ft²/°F/ft*	*0.39*
Thermal efficiency of net electric power generation, %	*15.5*	*Specific heat, Btu/°F/lb*	*1.115*
Core life before refueling, Mw-yr	*15*	*Coolant flow through core, single pass, gal/min*	*4,000*
Operating pressure in reactor, psia	*1,200*	*lb/hr*	*1.66 × 10⁶*

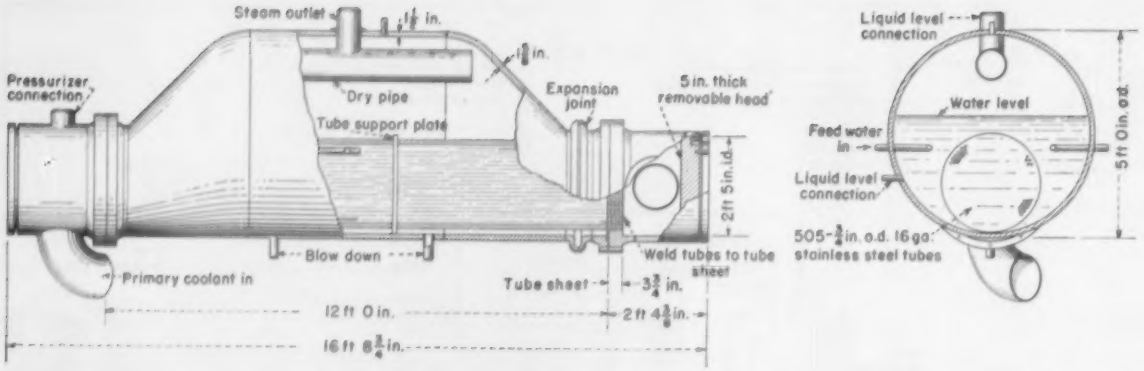


FIG. 3. Main steam generator, which is a single-pass horizontal shell-and-tube heat exchanger, is of standard construction except that tubes are welded to sheets to prevent radioactive water in tubes from leaking into steam system. Steam-generator pressure ranges from 200 psia at full load to 423 psia at no load. Valve maintains 192-psia steam pressure at turbine throttle

fuel used in each loading will be enough to operate the reactor for 15 Mw-yr, which means it can run at full power for 1½ years. Average operation at 60% of rated capacity permits the fuel to last 2½ years between reloadings.

Pressure vessel. Figure 4 shows the reactor pressure vessel,* which has a design pressure and temperature of 1,250 psi and 650° F. The shell material specified has good welding and mechanical properties; the internal cladding resists corrosion by coolant.

* Designed according to American Society of Mechanical Engineers Code for Unfired Pressure Vessels (N. Y., 1952).

Since total stresses in the pressure vessel, including thermal stresses induced by nuclear reactions in the walls, were calculated and appeared excessive, a 2-in. stainless-steel thermal shield was placed adjacent to the reflector. For operation with the coolant at 450° F, this shield reduces tensile stress

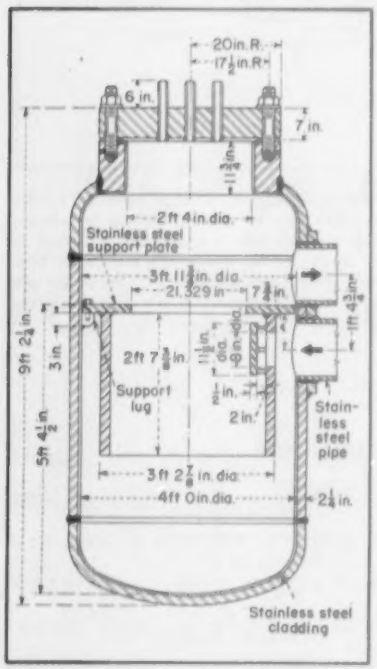


FIG. 4. Reactor pressure vessel shell is of ASME Type-SA 212 Grade-B fire-box-quality boiler-plate steel, is clad internally with 125-mil AISI Type-304 stainless steel. Standard ASME ellipsoidal heads are welded to about-6½-ft-long cylinder; top head is welded to 6-in.-thick cylinder to attach cover plate. Stainless-steel pipe sleeves welded to cover plate provide control-rod-drive mount

CALCULATIONS FOR . . .

. . . CRITICALITY. *These were made using three theories.*

Modified two-group theory, *which allows for multiplication in the fast group, is preferred over ordinary two-group theory because of the appreciable resonance absorption expected in the heavily loaded core.*

Three-group method, *coded for the Oracle computer, provides convenient means for studying the effect of varying numerous core parameters. Computation of group constants for the two and three-group calculations included the effects of inelastic scattering of neutrons in the stainless steel, and of chemical binding of hydrogen in water molecules.*

Thirty-group method, *coded for Univac, allows up to nine concentric regions of different compositions. It was used to estimate long-term reactivity changes in the reactor with nonuniform burnup of fuel. The thirty-group code, which accurately considers the neutron slowing-down spectrum in water, yields very satisfactory results for many aqueous homogeneous critical assemblies.*

All three methods gave comparable results for the critical mass of the cold, clean reactor; the hot, poisoned reactor; and the hot, fully-loaded reactor. The greatest difference is about 10% in critical mass, or about 4% in reactivity.

. . . CONTROL RODS. *Effectiveness of rods is determined by two theories.*

Modified two-group *calculations are made for an equivalent bare cylindrical reactor employing, at the rod surface, a fast-group boundary condition based on diffusion of fast neutrons into moderator within the rod (NU, Feb. '55, p. 18).*

Three-group three-region *calculation on the Oracle is applied to a central rod in a cylindrical, side-reflected reactor. The rod is regarded as a moderating region, surrounded by a thin absorbing shell opaque to thermal neutrons, semi-transparent to resonance neutrons, and transparent to fast neutrons.*

The modified two-group method gives 0.058 for the reactivity worth of the central rod, and 0.194 for the worth of all rods in the configuration. The Oracle method gave 0.067 for the central rod. Since the maximum reactivity excursion of the reactor is 0.14, the rods should be comfortably adequate.

. . . TEMPERATURE COEFFICIENT OF REACTIVITY. *Univac thirty-group method is used. The multiplication constant is calculated at 432° F for two reactor cases that are critical at 450° F, i.e., at beginning and end of operating cycle. In both cases, dk/dt is negative and larger than 10^{-4}/°F.*

in the wall from 24,000 psi to 17,000 psi. It also permits use of less concrete in the radiation shield.

Control-rod drive. To solve the major problem of introducing linear motion inside the high-pressure vessel, the mechanism shown in Fig. 5 is used. Control rods can be driven through seals because the system can tolerate a modest amount of leakage, provided it is collected and returned. To cut costs, all components are conventional except the seal.*

Control circuits. The reactor control system consists of two sections: operational circuits and safety circuits. The control circuit maintains reactor power at the level of the load demand by keeping exit-water temperature at about 450° F. Increased load causes more steam flow and lower steam temperature. This lowers coolant temperature, and a motor-driven demand-level potentiometer signals the servo to withdraw the regulating rod until power level again establishes 450° F coolant temperature. Conversely, lower load demand causes insertion of the regulating rod until reactor power level matches the new load condition.

If power level, as represented by neutron flux, exceeds the network's maximum setting, the servo reacts to insert the regulating rod and lower the power level. Thus, temperature is the main controlling factor up to the maximum power setting; then neutron flux becomes the controlling factor and overrides the temperature signal. A selector switch can transfer the regulating rod from servo to manual control.

The safety instruments and circuits are similar to those on many ORNL-designed reactors. Both reactor period and flux safety circuits are provided, neither of which can be overridden by operator action. Emergency scram buttons are located throughout the plant for use by personnel in case emergency shutdown is required.

For safety, the reactor can not be started unless the fission chamber (for detecting extremely low fluxes) is operating; this insures that at least one instrument is reading at low flux levels. The chamber is moved during startup so as to increase its effective range.

Shielding. To insure applicability to any site, the concrete shield is designed with the uneconomical assumption that ground excavation and rock

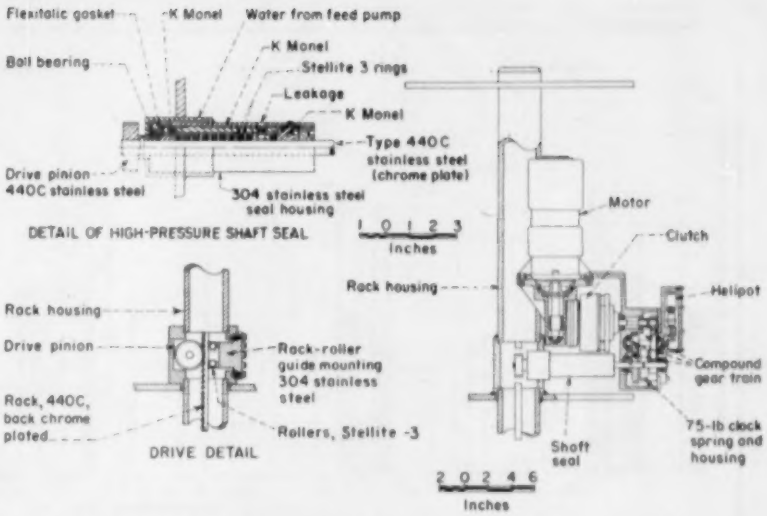


FIG. 5. Each control rod is driven by rack and pinion inside pressure-vessel cover. Motion is transmitted from cover-mounted motor package to pinion through semi-commercial seal. Number of seal rings and clearance determines pressure breakdown and resultant leakage. For 10 lb/hr leakage of 1,200-psi 600° F water, over-all length of seal is 6 in. and shaft clearance is 0.0003 in., with shaft ground to 0.0001-in. tolerance

shielding are impractical. As shown in Fig. 1, the shield forms separate compartments for the reactor and steam generator.

For the reactor operating at full power and with an arbitrarily defined permissible dose rate of 300 mrep per 56-hr work week, required thicknesses of ordinary concrete are: 9.3 ft around the reactor vessel, 4.0 ft around the steam generator compartment, and 7.9 ft above the reactor vessel.

In the reactor compartment, a metal lining sealed to the pressure vessel near its top makes it possible to flood the compartment when loading the core. One hour after shutdown, dose rate is 7.5 mrep/hr at the top of the unplugged and flooded reactor well.

The pit containing the reactor vessel is only 6 ft in diameter; it is located eccentrically below the 8-ft octagonal chamber over the reactor. This provides space for coffins and handling tools during unloading operations. A water-filled well alongside the reactor vessel provides for storage of spent fuel elements and also acts as a sump for leakage from seals and other components. Coolant pipes joining the reactor and steam generator pass through a tunnel in the shield wall. The tunnel is off-center relative to the reactor to prevent radiation streaming through it.

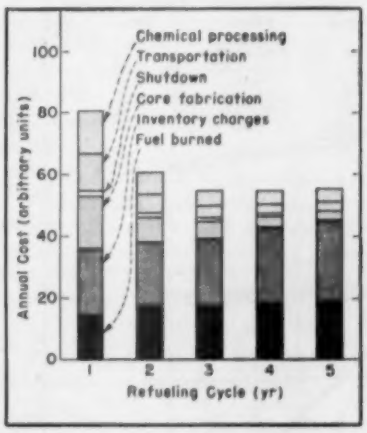


FIG. 6. Total fuel and related costs were computed for various loadings to evaluate effect of core life on costs. The 2½-yr cycle (15 Mw-yr) chosen is near minimum cost, but longer cycles are not unattractive

Cost Analysis

Major plant components were engineered sufficiently to enable several reliable manufacturers to quote fabrication costs; where there were no direct quotes, costs were estimated by comparing the component with similar items. Construction costs are believed realistic for a developed site similar to Oak Ridge. They would run substantially higher at remote locations because of higher labor and transportation costs.

Capital costs. Excluding develop-

(Continued on page 48)

* The rotary spindle seal was developed by Kuchler-Huhn Co., Philadelphia, Pa.

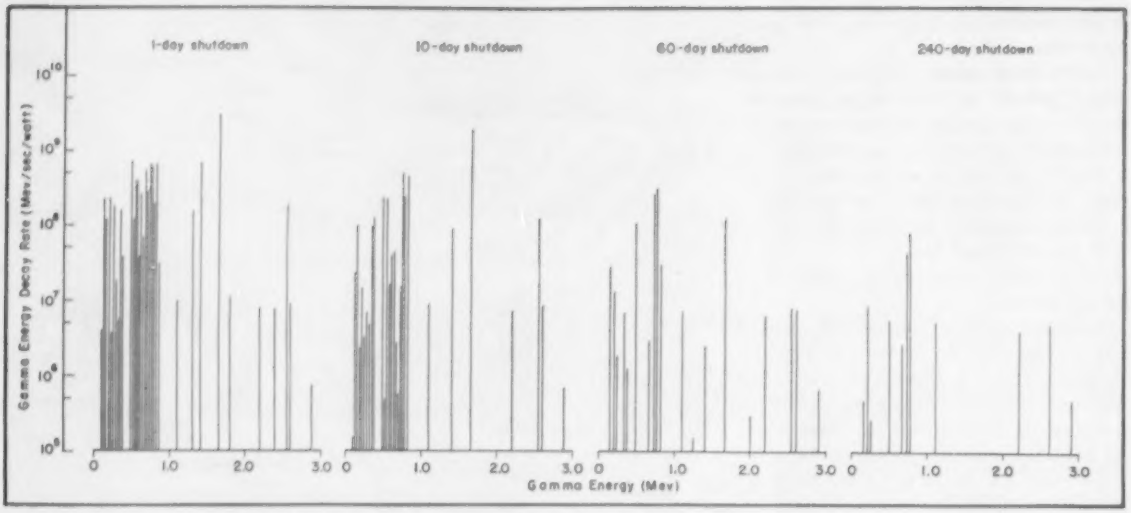


FIG. 1. Energy spectrum of decay gammas from gross fission products after 1,000 hours operation. Abscissa shows energy of gammas in table. The 0.663-Mev gamma of 33-yr Cs^{137} also is included although it is not an important contributor at these shutdown times. Data do not include Bremsstrahlung caused by fission-product betas

Energy Spectrum of Gammas from Gross Fission Products

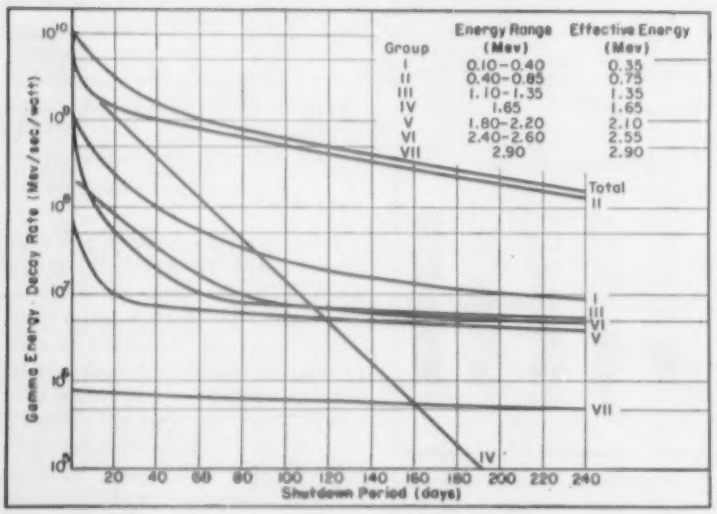


FIG. 2. Group distribution of gamma decay rates for 1,000 hours operation as function of time after shutdown

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ENERGY SPECTRUM calculations, whose results are shown here for gammas from thermal-fission products of U^{235} for various times after shutdown, are applicable to fission products from any thermal reactor using U^{235} as the fuel. The activities are expressed as percentages of saturation activity and are normalized to reactor power of 1 watt.

Figure 1 shows the energy spectrum of decay gammas after 1,000 hours of reactor operation and various shutdown times. Note the rapid decay of the many soft gammas. Figure 2 shows the totals of each of seven energy groups along with the over-all total for the gross fission products. Groups are

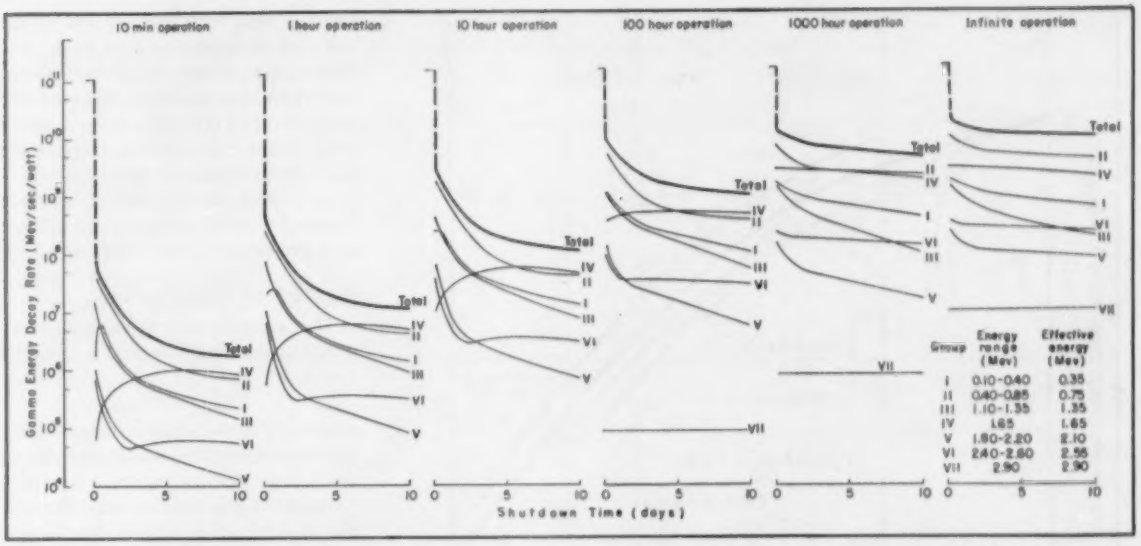


FIG. 3. Energy group distribution of gamma decay rates as function of time after shutdown for various times of operation. Dotted line, total decay rate from 10 sec to 4 hr after shutdown, is from integration of $0.90\tau^{-1.20}$, where τ is time after fission in sec (*4*); total decay rates are extrapolated to saturation values at shutdown. Total decay energy ranges from about 1.10×10^{11} Mev/sec/watt for 10-min operation to 1.6×10^{11} Mev/sec/watt for infinite operation

Knowledge of the energy spectrum of gamma rays from gross fission products is useful in calculating shielding for fuel elements taken from a reactor and in planning use of fuel used for radiation processing of foods, pharmaceuticals, and chemical products

used to simplify treatment of data. Effective energy of each group varies slightly with time after shutdown; thus, choice of representative energies is left to the user's discretion.

Various operating times. Figure 3 shows how various times of operation affect the total and group gamma decay rates. It indicates that relative rate distribution for 10 min to 100 hr operation does not change much beyond 2 or 3 days after shutdown. This means the important fission products do not reach saturation during this time of operation.

However, there is a marked change beyond the 100-hr operation because a few important fission products reach saturation before 1,000 hours. The values beyond a few days after shutdown for 1-, 10-, and 100-hr operation differ by factors of about 10, indicating that a linear interpolation on a semilog plot can be used for times up to 100 hours of operation. This interpolation can be extended to the 1,000-hr operation if shutdown times are such that the only contributing fission products are those that have not reached saturation in 1,000 hours of operation.

Immediately after shutdown, the total energy decays rapidly because of the short-lived fission products that reach saturation within short operating times. Since they reach saturation almost immediately, their contribution to the total decay energy is essentially the same regardless of operating time. The increase in total decay energy with operating time is caused by the buildup of longer-lived fission products.

Validity of Data

Figure 4 shows that the total decay rates agree very well with experimental work and other calculations.* The rate of decay disagrees slightly with the integral of the theoretical expression $(\frac{1}{4})(3.75\tau^{-1.2} + 96.0\tau^{-1.4})$ in the region of 1–10 days shutdown (*3*). This discrepancy can be due to the inequality between the beta and gamma decay energy rates at those times. The integral of the rule-of-thumb $1.26\tau^{-1.2}$ (*3*), is slightly lower than the values calculated here; the maximum deviation is less than a factor of 1.5. The

* Since only the gamma energy is considered here, the values by Borst and Wheeler, Lane and Brady, Turkevich and Brady, and the results of calorimetric experiment, all of which included both beta and gamma energies (*2*), are reduced by a factor of two and are corrected for 1,000 hours operation. It is assumed that the gamma and beta energies are approximately equal a few days after shutdown.

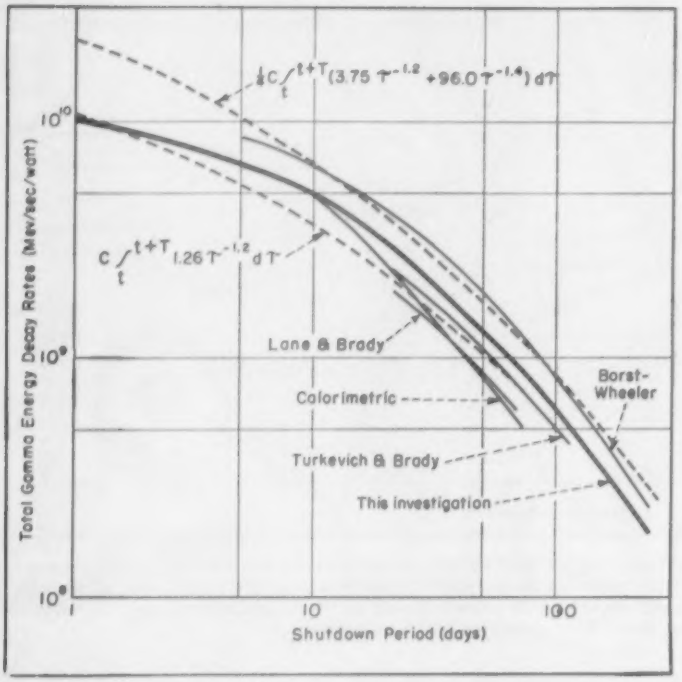


FIG. 4. Total gamma decay rate as a function of time after shutdown (1–240 days) for 1,000 hours operation. C is 3.25×10^{10} fissions/sec/watt

decay rate shown by the calorimetric curve is somewhat faster than the other reported values. The Borst-Wheeler curves are based on the early works of Borst on cyclotron irradiations of uranium and check within a factor of 1.5 over the range shown. The calculations of Turkevich and Brady, based on known beta and gamma energies and the fission yields of the different fission products, represent some of the later work on energy rates and are within a factor of about 1.2 of the values of this investigation.

Figure 5 shows that the total decay rates calculated here are within a factor of 1.6, or less, of the expression $1.26\tau^{-1.2}$, except at short shutdown times for short operating times. However, in the time interval from 10 sec to 1 day after fission, a better fit to the curve is $0.90\tau^{-1.2}$ (*4*).

Although spectrum values are more reliable for about 10 hours shutdown than for the 4-hr case because a few of the nuclides with half-lives near 4 hours were rejected, the discrepancy is not large since most of the rejected nuclides have low gamma energies or small fission yields.

Average energy. Experimental measurements of gross gamma activity from fission products after short operating times reveal an average attenuation coefficient corresponding to about 3 Mev for the first few minutes of decay and about 1.8 Mev for 1–2 hours of decay (*5*).

In Fig. 3, energy group IV, which is the 1.65-Mev gamma of La^{140}, is the most prominent energy for moderate shield thicknesses beyond a few days after shutdown. The La^{140} builds up as its parent Ba^{140} decays until about 134 hr after shutdown, at which time it will be in transient equilibrium with Ba^{140}. Energy group VI has the 2.55-Mev gamma of La^{140} as one of its components; this is evident beyond three days after shutdown.

Nuclides Included

The table lists the nuclides used in the calculations reported here. These calculations include 24 of the approximately 100 nuclides that emit gammas during the decay of U^{235} fission products (*1*). To simplify the calculations, the others are considered insignificant because of low fission yield, gamma energy below 0.10 Mev, and half-life less than 5 hr. Two short-lived daughter nuclides are used because of their relatively long-lived parents.*

Some very long half-life species are not used because shutdown times considered here do not bring their activities to an appreciable value compared to the total spectrum.† Some nuclides with rather high gamma energies are neglected because of their short half-lives.‡ The undetermined gammas from a few species are not used because they are too weak or low in energy.

Method of Calculation

The fission-product gamma-energy decay rate for each nuclide is given by

$$\Gamma_i = N_i F_i(T, t) \qquad (1)$$

where: Γ_i is the energy released from the ith nuclide, Mev/sec/watt of steady operation; N_i is a constant for each particular nuclide and is dependent on the fission yield, fission rate, radio-

* They are: 30-sec Rh^{106}, daughter of 1-year Ru^{106}; and 17.5-min Pr^{144}, daughter of 275-day Ce^{144} (*6*).

† For instance, 33-year Cs^{137}, with a 0.663-Mev gamma (*7*), contributes about 1.5% (*8*) of the total gamma-decay energy 8 months after shutdown of a reactor operated 11 days. Under the same time conditions, the $Zr^{95} + Cb^{95}$ mixture, with approximately 0.73- and 0.76-Mev gammas, contributes about 80% of the total energy. About 25 months after shutdown, the Cs^{137} contributes about 30% of the total energy and the $Zr^{95} + Cb^{95}$ mixture contributes about 9%. For longer times after shutdown, say 35 months, the Cs^{137} and $Ce^{144} + Pr^{144}$ mixture is roughly 95% of the total gamma energy.

‡ The delayed neutron emitter, 56-sec Br^{87}, has a small yield of a 5.4-Mev gamma (*1*). The 86-sec I^{136} has a 2.8-Mev gamma. Kr^{90}, with a half-life of 2.77 hours, has approximate gamma energies of 1.9 and 2.8 Mev (*9*). The 16.5-min Y^{94} has a 1.4-Mev gamma.

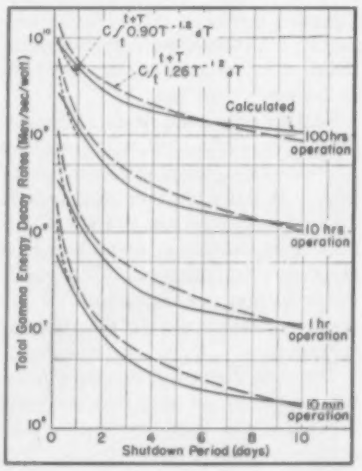


FIG. 5. Total gamma decay rates as a function of time after shutdown (4 hr to 10 days) for various times of operation

active decay scheme, and gamma energy of the ith nuclide; $F_i(T, t)$ is that fraction of the saturation activity of the ith nuclide that is present after t days shutdown following T hours of operation.

The value of N is the product of: y = fission yield, nuclei/fission; g = fraction of transitions that yield gammas, gamma/nuclide; E = gamma energy, Mev/gamma; f = fission rate per operating watt, fissions/sec/watt. The first three factors are given in the table along with the numerical value of N for each nuclide. The fission rate is (192 Mev/fission)$^{-1}$ (1.6×10^{-6} erg/Mev)$^{-1}$ (10^7 erg/watt/sec) = 3.25×10^{10} fissions/sec/watt. At saturation, a value of 5 Mev/fission is used as the gamma energy release of the decaying fission products (*9*).

For each radioactive nuclide considered, if the half-lives of precursive nuclides in the mass decay chain are of the order of a few minutes, the fraction of the saturation activity present after T hours operation and t days shutdown is calculated by

$$F_1(T, t) = (1 - e^{-\lambda_1 T})e^{-\lambda_1 t} \quad (2)$$

where λ_1 is the decay constant of the nuclide ($\lambda = 0.693/T_{1/2}$), and $T_{1/2}$ is the nuclide half-life (*10*). If the nuclide in question is a daughter of a long-lived nuclide

$$F_2(T, t) = \frac{\lambda_1 \lambda_2}{\lambda_1 - \lambda_2}\left(\frac{1 - e^{-\lambda_2 T}}{\lambda_2} e^{-\lambda_2 t} - \frac{1 - e^{-\lambda_1 T}}{\lambda_1} e^{-\lambda_1 t}\right) \quad (3)$$

is used, where λ_2 is the decay constant of the daughter. There is no need here to include the granddaughter order.

* * *

This article is a condensation of APEX-134 (1953) and includes modified data.

BIBLIOGRAPHY

1. C. D. Coryell, N. Sugarman, "Radiochemical Studies: The Fission Products," National Nuclear Energy Series IV-9 (McGraw-Hill Book Co., Inc., New York, 1951)
2. R. A. Day, C. V. Cannon, in vol. 1, p. 432, ref. (*1*)
3. K. Way, *Phys. Rev.* **70**, 115 (1946)
4. K. Way, E. P. Wigner, in vol. 1, p. 457, ref. (*1*)
5. N. Sugarman, *et al.*, in vol. 1, p. 371, ref. (*1*)
6. W. K. Ergen, ANP-59 (1951)
7. Circular 499 with supplements 1, 2, and 3 (National Bureau of Standards, U. S. Department of Commerce, Washington, D. C., 1950)
8. W. Rubinson, *et al.*, in vol. 1, p. 404, ref. (*1*)
9. S. Glasstone, M. C. Edlund, "The Elements of Nuclear Reactor Theory," p. 71 (D. Van Nostrand Co., Inc., New York, 1952)
10. E. Rutherford, J. Chadwick, C. D. Ellis, "Radiations from Radioactive Substances," ch. 1 (Cambridge University Press, Cambridge, England, 1951) (reprint with corrections)
11. D. Engelkemeir, *et al.*, ANL-4927 (1952)

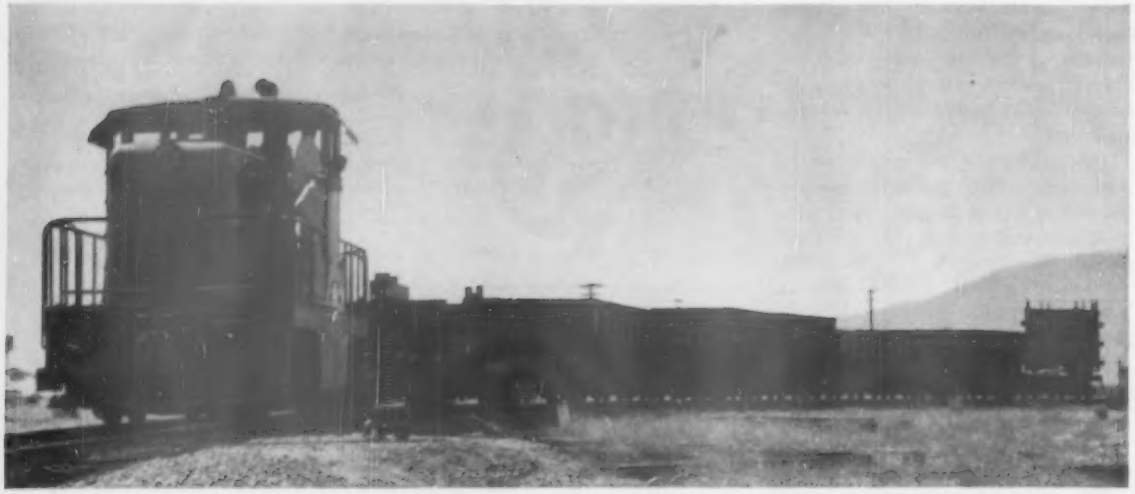
Nuclides Considered in Calculations*

Nuclide	Half-life	Fission yield (nuclide/fission)	Percent disintegrations (gamma/nuclide)	Energy (Mev/gamma)	Energy decay rate† (10^7 Mev/sec/watt)	Energy group‡
Sr^{91}	9.7h	0.050	0.40	1.30	88.4	III
			0.40	0.61	41.5	II
Y^{93}	10h	0.0600	1.00	0.70	143.	II
Zr^{95}	65d	0.0600	0.98	0.73	146.	II
			0.02	0.24	1.0	I
Nb^{95}	35d	0.0600	1.00	0.76	155.	II
Nb^{97}	60s	0.0620	1.00	0.75	158.	II
	74m		1.00	0.67	141.	II
Mo^{99}	67h	0.0620	0.13	0.73	20.0	II
			1.00	0.14	29.5	I
Ru^{103}	42d	0.0370	0.94	0.49	58.1	II
			1.00	0.04	5.0	I
Rh^{106}	30s	0.0052	0.02	2.90	1.03	VII
			0.01	1.25	0.23	III
			0.17	0.73	2.19	II
			0.17	0.51	1.54	II
Sb^{127}	93h	0.00094	0.16	0.72	0.37	II
I^{131}	8d	0.0044	0.15	0.64	1.44	II
			0.79	0.36	4.26	I
			0.06	0.28	0.27	I
I^{131}	8d	0.0240	0.15	0.64	7.83	II
			0.79	0.36	23.2	I
			0.06	0.28	1.47	I
I^{132}	2.4h	0.0360	0.50	0.60	34.5	II
			0.50	1.40	80.5	III
			0.027	2.00	6.21	V
I^{133}	22.4h	0.0460	0.01	1.40	2.18	III
			0.05	0.85	6.71	II
			0.94	0.53	77.7	II
I^{135}	6.68h	0.056	0.0195	2.40	9.12	VI
			0.0400	1.80	13.7	V
Xe^{135}	15.3m	0.056	0.30	0.52	29.6	II
Xe^{135}	9.2h	0.056	1.00	0.25	47.5	I
Ba^{140}	12.8d	0.061	0.40	0.54	44.7	II
La^{140}	40h	0.061	0.04	2.55	21.1	VI
			0.96	1.65	3.28	IV
			0.41	0.82	69.1	II
			0.45	0.49	45.7	II
			0.25	0.34	17.6	I
Ce^{141}	30d	0.0570	0.66	0.15	19.2	I
			0.01	0.32	0.58	I
Ce^{143}	33h	0.0540	1.00	0.20	36.8	I
Pr^{144}	17.5m	0.053	0.02	2.60	9.36	VI
			0.02	2.20	7.92	V
			0.05	1.10	9.90	III
			0.40	0.22	15.8	I
Nd^{147}	11d	0.026	0.07	0.58	3.71	II
			0.93	0.04	3.27	I
Sm^{153}	47h	0.0015	1.00	0.11	0.561	I
			1.00	0.07	0.357	I
Eu^{156}	15.4d	0.00013	0.60	2.00	0.528	V

* Decay chains, half-lives, gamma-emitting nuclides, and fission yields are mostly from ref. (*1*). Gamma energies and decay schemes are primarily from ref. (*7*).

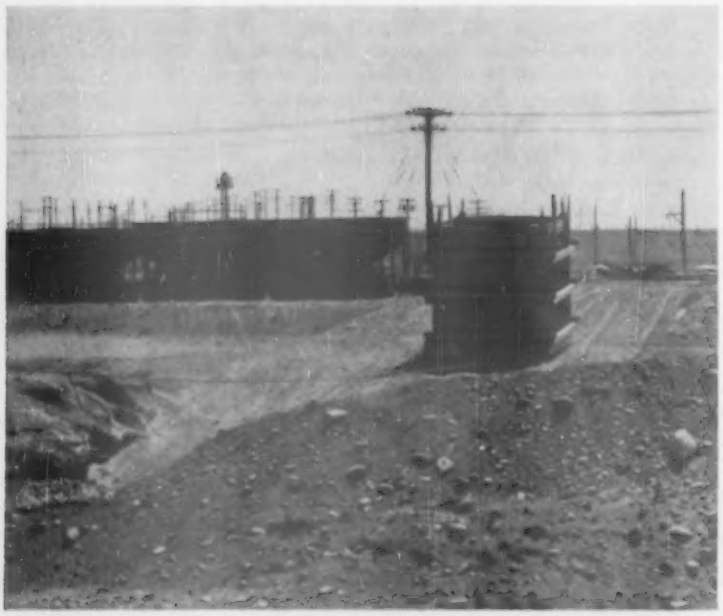
† Includes a factor of about 1.04 to correct the fission yield to a new standard of 6.37% (*11*).

‡ For definition of energy groups, see Figs. 2 or 3.



1 TEN EMPTY CARS separate locomotive from 6-ton piece of radioactive "junk" in trip from separations plant to burial ground. Remotely operated crane in separations plant lifted "hot" concentrator with attached piping from cell in bottom of canyon, placed it in metal-lined wooden box on railroad flatcar, and bolted down lid. With hot equipment inside box, no one can stay within 600 ft of it for more than half-hour

How Hanford Discards "Hot" Equipment



3 WITH FLATCAR IN PLACE AT SIDING, cat drags box off flatcar, across siding, and down ramp into trench

GETTING RID OF "HOT" VESSELS that fail and equipment that wears out at plutonium-separation plants requires extreme care.

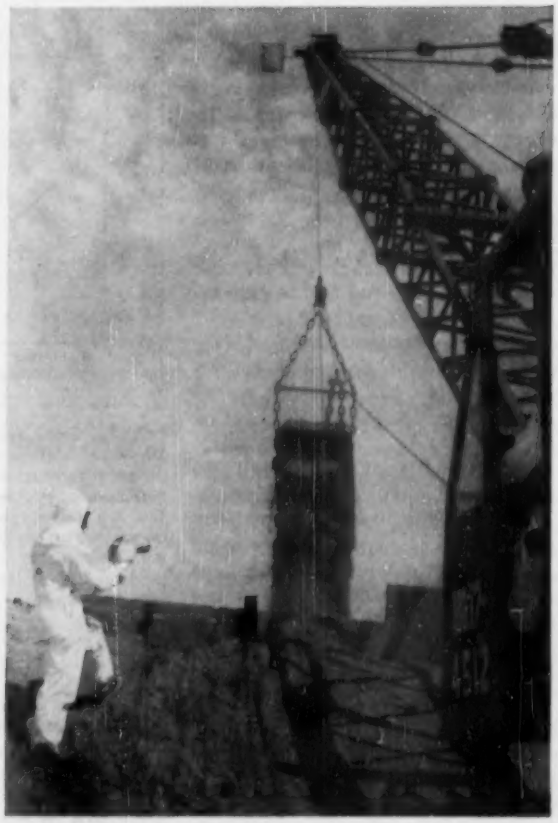
General Electric solves the problem at Hanford by burying them in vacant areas of the uninhabited 600-square-mile plant reservation. Pictured here is a typical burial operation.

Although even the dismantling of the Chalk River reactor apparently did not involve burying anything as big as the concentrator shown here, such operations are done on a routine basis at Hanford. Each burial is preceded by a dry run, during which the box is hauled empty from the separations plant to the burial ground to be sure it will pass all gate posts and power lines safely. If, on the appointed day, the wind blows faster than 10 miles/hr, the operation is postponed.

In the operation shown here, the box was underground before the end of the work shift. A man then could safely walk on the packed earth over it.

2 AT BURIAL GROUND, locomotive stops at concrete siding at head of long trench perpendicular to rail line. Steel cable, attached to box and looped along train to locomotive, is attached to "cat." As locomotive moves slowly down track, cat lumbers off toward other end of pit, unpeeling cable from cars. Signalman on crane boom (right) signals instructions to locomotive engineer.

4 DRAGLINE OPERATOR adjusts mirror on end of crane boom so that he can see over protective embankment while burying box



5 DRAGLINE BURIES BOX. Although crane was stationed behind pile of dirt and rock, monitor watched for "sky shine"—radiation reflected downward by dust and vapor

High-Energy Nuclear Physics

FOR THESE QUESTIONS . . .	. . . ARE THESE ANSWERS? . . .
How large is a proton?	Electron-scattering experiments give proton radius of $0.7-1 \times 10^{-13}$ cm.
Is the mu-meson a "heavy electron"?	Mu-pair production follows same law as for electron pairs.
Why do heavy mesons decay so slowly?	Decay may have to conserve a new quantum quantity, "strangeness".

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THIS ARTICLE IS an interpretive account of three of the many themes discussed at the fifth Rochester high-energy conference. An attempt has been made to supply sufficient background material so that latest results can be viewed in proper perspective. To obtain a basis for comparison, as well as necessary background material, the reader is referred to the author's summary of the third conference (*1*).*

The topics discussed here are:

1. Structure of the well-known elementary particles: Specifically, the results of two basic experiments, one on the proton and one on the μ-meson.

2. The new unstable particles: These appear to require, for the understanding of their production and stability properties, a new type of conservation principle, the nature and implications of which are now under active investigation.

3. Pion-nucleon interactions: Very-low-energy scattering experiments and mesic atoms are discussed. Here there has been considerable theoretical progress, in that there now exists, for low-energy phenomena, a semi-phenomenological field theory capable of reproducing the main features of the observations.

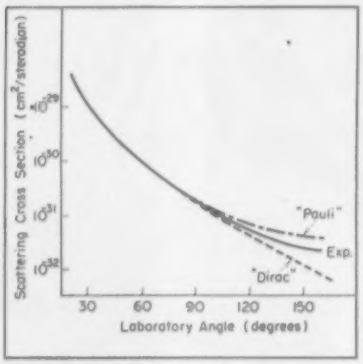


FIG. 1. Cross section for scattering of 189-Mev electrons by protons. Solid curve (experimental results) lies above one that assumes proton obeys Dirac equation. The top curve takes the proton's exact, anomalous magnetic moment into account. Both theoretical curves assume point proton. Curves illustrate Hofstadter's results rather than accurately reproduce them. For more accurate version see Hofstadter and McAllister, *Phys. Rev.* 98, 217L (April 1, 1955)

Structure of Elementary Particles

The central problem of high-energy nuclear physics is the nature of the so-called "elementary particles." The most familiar of these are the photon, electron-positron, proton-neutron, and neutrino. Recent additions, the μ- and π-mesons, are by now relatively well-established members of the family. The most recent candidates, a whole host of heavier particles will be the subject of the next section.

The term "elementary" is somewhat misleading, since many of these particles are unstable and decay spontaneously into other "elementary" particles (e.g., the neutron, which undergoes β-decay). However, these particles are characterized by a quasi-stability, since their lifetimes are very long compared with the time that would be required for the decay products to fly apart in the absence of the stabilizing factor that holds them together. (This time is, characteristically, $\sim 10^{-23}$ sec.)

Structure of the proton. With refinement of experimental techniques, it is becoming possible to carry out investigations into the "structure" of elementary particles. Thus, some years ago, a series of studies were made on the neutron-electron interaction (*2*) in an attempt to elucidate the charge-structure, if any, of the neutron. The results of these experiments were negative in the sense that no effects were

* The complete proceedings of preceding conferences have been published by Interscience Publishers, Inc., New York, who will also publish the proceedings of this conference.

observed that could be ascribed to a finite extension of charge (as would have been the case, for instance, if the neutron were a positive core surrounded by a cloud of negative mesons).

An experiment of similar intent has now been carried out for protons, with an apparently positive result. This experiment was performed by Hofstadter and co-workers (*3*). Their results on the scattering of 189-Mev electrons by protons are indicated in Fig. 1.

It is clear that effects of the anomalous proton moment are required to account for the observed scattering. However, since the full effect of the moment overcorrects the theory, one can conclude either that the proton presents to the electrons involved in this experiment an "effective" magnetic moment which is less than its static moment, or that the proton has a finite size. In the latter case, the decrease at large angles of the observed as compared to the predicted scattering is due to a "form factor" which is a measure of the spatial extent of the spread in proton charge or proton moment (or both). The proton size required to account for the observations is $\sim$0.7–1 fermi. (1 fermi = 10^{-13} cm.)

Further measurements, at other energies, should result in a choice between the alternative explanations. In any event, this lovely experiment demonstrates for the first time the possibility of observing directly effects of the structure of elementary particles.

Mu-pair production. Among the other well-known elementary particles, the μ-meson occupies a somewhat anomalous position. It is a particle of odd-half-integral spin (probably $\frac{1}{2}$) which does not interact with nucleons and whose only role appears to be that of serving as the decay-product of the π-meson. It has been assumed that the μ-meson is some kind of a heavy electron, but earlier attempts to demonstrate this failed, essentially because of experimental difficulties (*4*). Some preliminary results reported by Panofsky from Stanford indicate that $\mu^{\pm}$ pairs can be produced by photons in the electric fields of nuclei. The cross section is as calculated for the production of electron-positron pairs, except that the μ-meson mass is substituted for that of the electron. While this result seems to conform to the picture of the μ-meson as a heavy electron, it still leaves many questions unanswered (such as why the π-meson does not decay directly into an electron-neutrino rather than, as it does, into a μ-neutrino pair).

Obviously, we still have much to learn about elementary particles.

What the Rochester Conference Revealed

In comparing this Rochester conference with its predecessors, the steady growth both of interest and progress in the field of high-energy nuclear physics is most impressive. It is noteworthy that this growth is not simply a result of the construction of high-energy accelerators and of the improvement in the experimental techniques for their utilization. The field of cosmic-ray research, especially as applied to the discovery and study of the properties of the new unstable particles, has kept pace by virtue of a steady improvement in the utilization of cloud-chamber and nuclear-emulsion techniques.

One aspect of this year's discussions with which this reviewer was impressed was the high correlation between the main theoretical efforts and the experimental investigations currently being carried on. In major part, this is a result of the accumulation of extensive and reliable data on many aspects of high-energy nuclear physics, which stand as an inviting challenge to theoretical explanation. In part, too, this is due to a certain measure of theoretical success, in the last year or so, in explaining and correlating some of these data, which has given impetus and encouragement to attempts to include the rest of the data into the theories.

However, in no small measure, the shift in emphasis of the theoretical work from the abstract towards the concrete represents a partial acknowledgment of the inability of meson field theories, in their present stage, to provide much more than a guide for setting up phenomenological theories which can serve, on the one hand, to correlate the experiments, and, on the other hand, to enable us to extract from the experimental information those significant physical aspects that may eventually point the way towards a correct theory. Whether the tendency towards such an approach represents a lowering of theoretical sights or whether it merely denotes a stage of preparation for new advances remains, of course, to be seen. In any event, one consequence is that the usefulness of dividing this type of discussion into theoretical and experimental aspects has, to a very large extent, vanished.

Heavy Mesons and Hyperons

If our understanding of the well-known elementary particles seems incomplete, we may always be consoled by considering the situation with regard to the newer elementary (called, alternatively, "fundamental," "heavy-unstable," or just "curious") particles. First discovered in cosmic radiation and now produced relatively copiously by the Bev proton synchrotrons at Brookhaven and Berkeley, their main features are now being ascertained.

These new particles are conveniently classified into two groups: **heavy mesons,** of mass intermediate between the π-meson (pion) and the nucleon; **hyperons,** of mass greater than that of the nucleon. The main properties (as known at the time of the conference) of some of these are briefly summarized in the table on p. 36.

The problem is to understand how it is possible that these particles are produced so copiously in nucleon-nucleon and pion-nucleon collisions, which indicates strong interactions with the pion-nucleon field, and still decay so slowly. (Strong interactions should give rise to rapid decays.)

One possibility is that these particles represent bound, metastable states of two or more pions (in the case of heavy-mesons) or a nucleon and one or more pions (for the hyperons), which owe their metastability to some kind of angular-momentum selection rule. This would, for example, be the case if the bound system had very high angular momentum, which would then have to be carried off in the decay. This explanation cannot be excluded on the basis of the present evidence, although it appears difficult to account in any detail for the observed spectrum of particles.

Associated production and "strangeness." Another explanation of the stability of the new particles is the hypothesis of "associated production." This hypothesis states that the interactions, in which the particles are produced, are strong only when a pair

of particles is involved, but weak for a single particle. Thus the particles are easily produced in pairs but, since they must decay individually, decay is slow (*5*).

Present experimental evidence, especially from accelerator investigations, indicates that the particles are indeed produced in pairs, although it is not yet proved that this is always so (*6*).

The hypothesis of associated production implies some kind of selection rule that governs the production and decay of those particles. Since selection rules in quantum mechanics usually imply the existence of quantum numbers, which are conserved in the various possible reactions, it is tempting to invent a new quantum number and corresponding conservation principle to explain the observations. Schemes of this type have been advanced by Gell-Mann (*7*) and by Pais (*8*). In their most elemental form the new schemes are as follows: We associate with each particle-type a quantum number, which has been called the "strangeness," to which we assign integral values, both positive and negative, according to the scheme illustrated in the box on the right. Those reactions are possible (fast) in which we conserve (a) angular momentum (thus, fermions with half-integral spin can only be produced in pairs), (b) charge, and (c) "strangeness." Those reactions are forbidden (slow) in which the strangeness changes by one unit, and even more forbidden if strangeness changes by more than one.

It turns out that the preceding scheme is not only consistent with observations, but is also useful in unraveling rather complicated-appearing phenomena observed both in cosmic-ray and accelerator experiments. There are, as yet, no serious contradictions, although there are some problems. For example, we need to understand or reduce the number of observed heavy mesons; some of these appear to be demonstrably different from others (*9*), while the scheme has room for only one or two types.

The most interesting problem is, of course, to understand the physical meaning of the scheme, if it should turn out to be true. To what does "strangeness" correspond? Usually, quantum numbers have their classical analogues in well-understood conservation principles (energy, charge, angular momentum), but this is not always the case. Thus, the isotopic-spin quantum number, which has come to be widely accepted and used in understanding pion-nucleon phenomena, does not easily lend itself to simple physical interpretations (although it can be associated with the operation of particle identification).

In any event, serious thought is being given to the finding of a physical basis for "strangeness," and much of interest, and possibly something very fundamental, should emerge.

HEAVY MESONS, HYPERONS, and "STRANGENESS"

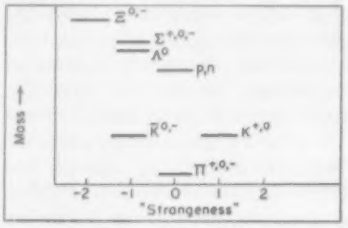
Heavy mesons are particles of mass intermediate between the π-meson and the nucleon; the hyperons are particles of mass greater than that of the nucleon. The following table lists some of the facts known about them:

Type	*Particle*	*Mass* (m_e)	*Decay scheme*	*Q-value* (*Mev*)	*Mean-life* (*sec*)
Heavy Mesons	$\tau^{\pm}$	965	$\pi^{\pm}+\pi^{+}+\pi^{-}$ $\pi^{\pm}+2\pi^{0}$	75	5×10^{-9}
	θ^{0}	965	$\pi^{+}+\pi^{-}$	214	1.5×10^{-10}
	$\chi(\theta^{\pm})$	955	$\pi^{\pm}+\pi^{0}$	212	$\approx10^{-9}$
	$K^{\pm}_{\mu 2}$	920–960	$\mu^{\pm}+\nu$		$\approx10^{-9}$
	$K_{\mu 3}(\kappa)$		$\mu+(2\nu)$ $\mu+\nu+\pi^{0}$?		
	K_{e3}		$e+(2\nu)$		
Hyperons	Λ^{0}		$p+\pi^{-}$	37	3.8×10^{-10}
	Σ^{+}		$n+\pi^{+}$ $p+\pi^{0}$	110	$\approx0.5\times10^{-10}$
	Σ^{-}		$n+\pi^{-}$	"	"
	Ξ^{-}		$\Lambda^{0}+\pi^{-}$	60	$\sim10^{-10}$

Many more details are available in the literature (16). For example the number of different heavy mesons could perhaps be reduced by classifying some of those shown as alternative decay modes of the same particle, since their masses could be equal. Nor have we included all of the particles for which there is now or will soon be evidence. However, from the data included certain regularities can be seen.

Thus, it appears (from the decay schemes) that hyperons are all particles of half-integral spin (fermions) as is the nucleon; heavy mesons, with the possible exception of the last two listed, are integral-spin particles (bosons) as is the pion. Furthermore, their lifetimes fall within a relatively small range and are relatively long compared with what one might anticipate from the ease with which they are produced.

It is this problem of the stability of the strange new particles that has led to the introduction of the hypotheses of "associated production" and the conservation of "strangeness" as discussed on p. 35ff. "Strangeness" quantum numbers for the particles listed in the table above are given in the diagram to the right.



Pion-Nucleon Interactions

Since the pi-meson is the "carrier" of nuclear forces, understanding the interactions of pions and nucleons is basic to understanding nuclear forces. The same meson field theory from which we hope, eventually, to be able to derive nuclear forces must yield the properties of the various meson-nucleon interactions.

Even two years ago, the main features of meson-nucleon interactions in the low-energy range, say up to meson kinetic energies of ~200 Mev, were fairly clear (*1, 10*).

In the past year considerable effort has been devoted to better understanding of meson-nucleon interactions at very low meson energies. The importance of such experiments is that

they yield information concerning the meson-nucleon interaction in the s-state since, at very low meson energies, the angular-momentum barrier strongly inhibits the otherwise predominant p-wave resonant interaction. It is worthwhile discussing some of these experiments, not only because of their bearing on the properties of the meson field, but also because they indicate a formidable development of experimental techniques in meson physics.

At low meson kinetic energies, it becomes very difficult to use counters for meson detection because of the short range of the mesons. Therefore effort has been devoted to the direct observation of meson scattering by the protons in nuclear emulsions or hydrogen-filled cloud chambers. Measurements of angular distributions in low-energy π-p scattering enable a determination of the signs of the nucleon-meson forces through observation of interference between nuclear and Coulomb scattering. Constructive interference means that Coulomb and nuclear forces have the same sign (i.e., the forces are both attractive or both repulsive). Since the Coulomb force is known (repulsive for $\pi^+ + p$; attractive for $\pi^- + p$) the nature of the interference yields the sign of the nuclear force. From such observations it is generally concluded that the s-wave phase-shift is positive for scattering in the $T = \frac{1}{2}$ state (T = total isotopic spin) and negative in the $T = \frac{3}{2}$ state, and that the p-wave phase shift is positive in the resonant state.

Meson-nucleon interactions at essentially zero energy have also been investigated through the properties of mesic atoms as discussed on this page. Results of low-energy experiments of this type are not yet in complete agreement, but they appear to be converging toward a common answer. The theoretical situation with regard to s-wave pion-nucleon scattering is not nearly in such good shape. No present meson theory can account for s-wave scattering.

Chew's nonrelativistic theory. Important theoretical advances have come mainly as a result of efforts by Chew (*11*) to develop a meson theory valid in the low-energy (nonrelativistic) approximation. Main assumptions in Chew's theory are:

- The meson-nucleon interaction is of the form $\boldsymbol{\sigma} \cdot \mathrm{grad}\phi$, where $\boldsymbol{\sigma}$ is the nucleon spin vector and ϕ the meson wave function. This "gradient" interaction favors p-wave scattering.
- The Hamiltonian for the meson-nucleon system has a form such that the interaction is "charge-independent." This requires the introduction of isotopic spin in appropriate fashion (*12*).
- The nucleon is assumed to have a finite extension in space—of the order of its Compton wavelength, $\hbar/Mc = 0.25$ fermis. This has the effect of introducing a cutoff which reduces the importance of large meson momenta, and makes it possible to obtain finite results from a perturbation calculation.
- In the nonrelativistic limit, the nucleon is assumed to have infinite mass as compared with the meson. This assumption is later relaxed, somewhat, in that Chew takes into account some effects of nucleon recoil following meson emission, to order v/c in nucleon velocity.

By using these approximations, calculational techniques made possible by recent advances in the manipulation of field theories, and high-speed computing machines, Chew has demonstrated that it is possible to account for the $T = \frac{3}{2}$, $J = \frac{3}{2}^+$ scattering resonance, as well as the photoproduction of both charged and neutral mesons from hydrogen (*11*).

More recent field-theoretic investigations have been devoted mainly to the demonstration that it is possible to obtain unambiguous results in the nonrelativistic limit from a completely relativistic meson field theory (*13*). In particular, Low has shown that the approximations of Chew follow from a more general, relativistic (and presumably correct) formulation of the theory.

It would be inappropriate to end this survey of last year's progress without mention of a great set-back to high-energy physics—indeed to all physics—by the death of Enrico Fermi, whose main activities in the last years of his life were in this field. Fermi has left a tremendous and uneradicable imprint on the field, not only by his impact on those who were fortunate enough to work with him directly, but on all who came into contact with his voice and his work. His influence will benefit the field for many years to come.

* * *

The organizers of the fifth Rochester conference did the superb job that we have come to expect of the conference committee. However, we owe a special debt of gratitude to its head, R. E. Marshak, for the zeal, skill, and ingenuity with which he overcame formidable obstacles raised by laws concerning the issuance of visas to foreign visitors.

Mesic Atoms

Negative mesons almost always settle into atomic orbits rather like ordinary electron orbits after being slowed down by the usual ionization energy-loss processes. As with electrons, transitions to lower orbits occur with accompanying emission of characteristic X-rays. Unlike electrons, the mesons are eventually captured by the nucleus. Also unlike electrons, the mesic orbits lie rather close to the nucleus; in fact the meson spends a fair amount of its time inside the nucleus. Thus mesic energy levels and consequently mesic X-rays are sensitive to the nature of the interaction between negative meson and nucleus (14).

The groups at Carnegie Institute of Technology and Rochester have accurately determined the energies of π^- mesic X-ray lines (15). They find that the frequency of the $2p \rightarrow 1s$ transitions in a number of light elements, from Li through F, disagree with the calculations unless the non-Coulomb meson-nucleon interaction is taken into account. Conversely, assuming that all other interactions are known, the measurements can be used to determine the interaction (actually, some combination of the two s-wave phase-shifts) between pions and nucleons at essentially zero kinetic energy.

BIBLIOGRAPHY

1. B. T. Feld, NUCLEONICS **11**, No. 2, 42 (1953)
2. B. T. Feld, "Experimental Nuclear Physics," vol. 2, p. 240, E. Segre, ed. (John Wiley and Sons, New York, 1953)
3. R. Hofstadter, B. Hahn, A. W. Knudsen, J. A. McIntyre, *Phys. Rev.* **95**, 512 (1954)
4. B. T. Feld, A. Julian, A. C. Odian, L. S. Osborne, A. Wattenberg, *Phys. Rev.* **96**, 1386 (1954)
5. A. Pais, *Phys. Rev.* **86**, 663 (1952)
6. W. B. Fowler, R. P. Shutt, A. M. Thorndike, W. L. Whittemore, *Phys. Rev.* **93**, 861 (1954)
7. M. Gell-Mann, *Phys. Rev.* **92**, 833 (1953)
8. A. Pais, *Physica* **19**, 869 (1953)
9. R. H. Dalitz, *Phys. Rev.* **94**, 1046 (1954)
10. M. Gell-Mann and K. M. Watson, in "Annual Review of Nuclear Science," vol. 4 (Annual Reviews, Inc., Stanford, Calif., 1954)
11. G. F. Chew, *Phys. Rev.* **95**, 1669 (1954)
12. G. Wentzel, "Quantum Theory of Fields" (Interscience Publishers, New York, 1949)
13. N. M. Kroll, M. A. Ruderman, *Phys. Rev.* **93**, 239 (1954); M. Gell-Mann, M. L. Goldberger, *Phys. Rev.* **96**, 1433 (1954); F. E. Low, *Phys. Rev.* **96**, 1428 (1954)
14. S. Deser, M. L. Goldberger, K. Baumann, W. Thirring, *Phys. Rev.* **96**, 774 (1954)
15. M. Stearns, M. B. Stearns, S. DeBenedetti, L. Leipuner, *Phys. Rev.* **97**, 240 (1955)
16. Proceedings of the Padua International Congress on the Heavy Unstable Particles, *Nuovo Cimento*, **12**, supplement 2 (1954)

Absolute

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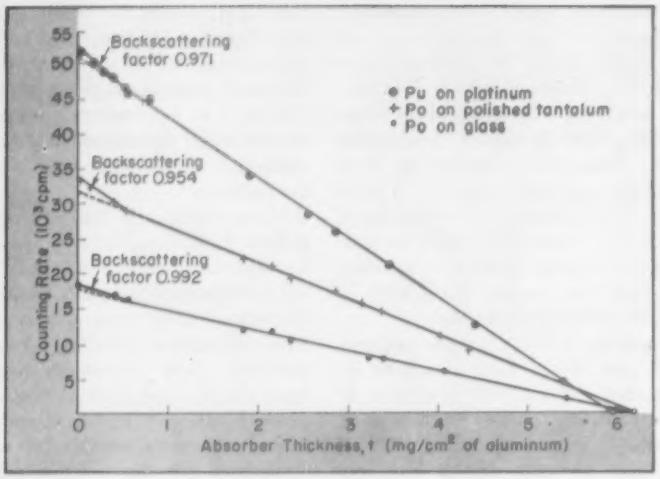

Backscattering factor 0.971
Backscattering factor 0.954
Backscattering factor 0.992
• Pu on platinum
+ Po on polished tantalum
° Po on glass
Counting Rate (10³ cpm)
Absorber Thickness, t (mg/cm² of aluminum)

FIG. 1. Alpha absorption curves in 2π geometry. Straight line bends up as zero thickness of absorber is approached because backscattered alphas are then able to penetrate the absorbers; backscattering factors are shown

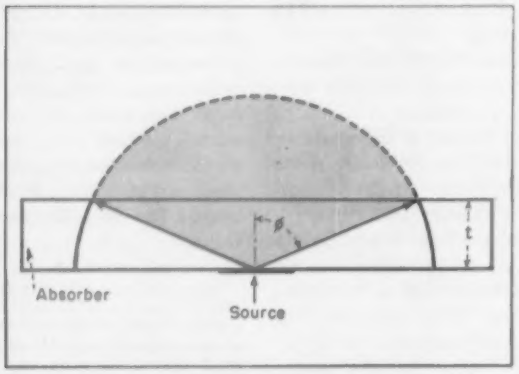


FIG. 2. Paths of alpha particles in absorber explain shape of absorption curve. Shaded region contains paths of all alphas that can reach detection

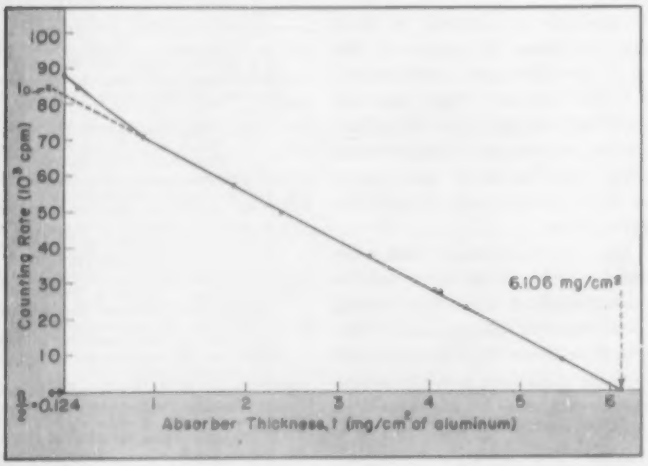


FIG. 3. Absorption curve for thick Po sample

THIS ARTICLE first considers alpha absorption techniques using a 2π chamber (*1*, *2*). Range, backscattering, and self-absorption can be determined from the absorption curve. Then low-geometry systems are discussed in terms of the basic equation for the "geometry factor" and the techniques employed to build and check working chambers.

Assay in 2π Geometry

Alpha absorption in a 2π flow counter uses absorption chamber (*3*), circuitry (*4*, *5*), and absorbers (*6*) that have been described in a previous article in NUCLEONICS (*7*).

Figure 1 shows typical absorption curves for monoenergetic alpha particles in 2π geometry. To understand the straight-line segment of the absorption curves consider Fig. 2, which shows paths of alpha particles through an absorber. Let

t = absorber thickness
I = counting rate at that thickness, t
$2I_0$ = absolute disintegration rate
r = range of alphas in absorber

It can be seen that only particles whose paths lie inside the spherical sector of half-angle ϕ will reach the sensitive volume of the chamber. Those traveling outside the sector will be absorbed. At zero thickness of absorber, this sector becomes a hemisphere. It follows that the fraction of upwardly emitted radiation that will be counted at absorber thickness, t, is equal to the ratio of the solid angle

* PRESENT ADDRESS: Mobay Chemical Company, c/o Monsanto Chemical Company, St. Louis 4, Missouri.

Alpha Counting

For activities below 10^5 dpm, absorption techniques in 2π geometry determine alpha count and range, backscattering, and self-absorption as well. For high activities (10^5–10^9 dpm) low-geometry collimated counter gives 0.1% accuracy

Ω at the vertex of the sector to 2π, half the total solid angle, that is

$$\frac{I}{I_0} = \frac{\Omega}{2\pi}$$

but, $\Omega = 2\pi(1 - \cos\phi) = 2\pi\left(1 - \frac{t}{r}\right)$

thus, $$\frac{I}{I_0} = 1 - \frac{t}{r}$$

$$I = I_0 - I_0\frac{t}{r}$$

Thus the absorption curve, neglecting backscattering, is a straight line whose intercepts are true counting rate and particle range. In practice I_0 cannot be measured directly because low-energy backscattered alphas cause the curve to bend up as zero thickness of absorber is approached, but the equation of the straight-line portion of the absorption curve can be determined with precision by means of a least-squares analysis of its points. The intercept of this straight-line portion on the counting-rate axis gives the absolute rate of emission in the upward direction.

Determining Range

Since one intercept of the line is the range, this system also affords a means of determining particle range and energy. An extremely thin sample on a highly polished surface is essential for good results. Samples volatilized on highly polished material have proven satisfactory.

A range of 6.23 mg/cm² in aluminum was determined for each Po sample shown in Fig. 1 by least-squares analysis of the points on the curve. The Po^{210} range in air is 3.83 cm (*8*); thus the stopping power of 1 cm of air must be equal to that of 1.627 mg/cm² of aluminum under these conditions. Using this figure, the range in air of any emitter can be determined, and its energy calculated.

In Fig. 1, the Pu^{239} sample is clearly distinguishable from the Po^{210} samples because of the difference in range. The range of 5.95 mg/cm² determined from a least-squares analysis of the absorption curve of Pu^{239} corresponds to 3.66 cm of air. This implies energy of 5.14 Mev, in agreement with values given in the literature. This method of range determination has helped identify unknown alpha emitters.

Backscattering

The difference between the measured count with no absorber present and the intercept I_0 is a measure of the contribution from backscattered alpha rays:

Radiometric vs Geometric Calibration of Low-Geometry Chambers

There are two general methods for calibrating low-geometry counters: radiometric and geometric. Radiometric calibration involves counting standards of known disintegration rate, and determining the ratio of observed counting rate to actual disintegration rate. Geometric calibration involves measuring the critical dimensions of the low-geometry arrangement and computing the solid angle through which particles emitted from a sample must pass in order to be counted.

Radiometric calibration is a simple process, but its accuracy depends upon the certainty with which disintegration rates of the standards used are known. These disintegration rates, even if correctly established originally, may change because of contamination or loss of activity.

Geometric calibration is painstaking and only as accurate as the measurement of critical dimensions that affect the geometry. These dimensions are: radii of collimating holes; distance between holes; perpendicular distance from top of sample to holes; and radius of sample deposit. There were a number of features inherent in the design and construction of the low-geometry counters which made physical measurement of these dimensions impossible with the degree of accuracy desired. The orifices are not truly circular; the plane of the orifices is not sufficiently well-defined. In some chambers, distance from top of sample to orifice plane varies with thickness of sample mount. Critical dimensions are subject to change because of abrasion of geometry-defining apertures during decontamination and because of wearing away of the tapered plug with use.

We use a combination of these two. A standard low-geometry chamber was designed and constructed. Its dimensions could be so accurately measured that the over-all error in geometry factors would not exceed 0.30%. This chamber is used to evaluate radioactive samples which in turn are used for radiometric calibration of other low geometry counters.

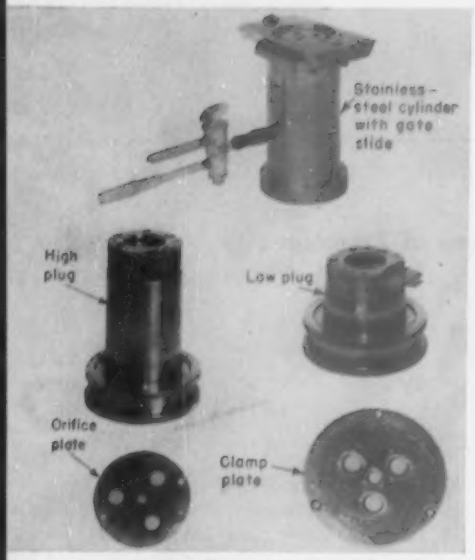


FIG. 4. Components of standard low-geometry chamber

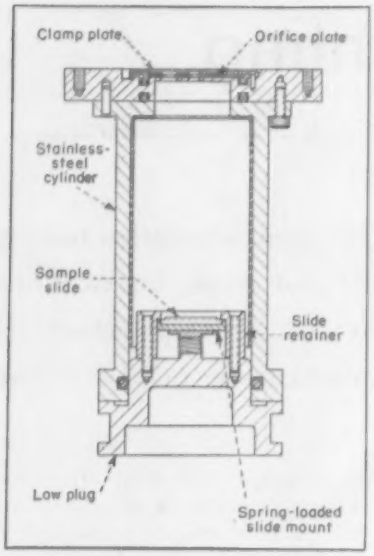


FIG. 5. Standard low-geometry chamber. Low plug shown in position; a high plug is also available (see Fig. 4)

thus for work of high precision it is desirable that backscattering be determined for each sample. Backscattering varies not only with the atomic weight of the backing, but also with sample thickness and with the state of the backing surface. For example, backscattering from a sample mounted on highly polished tantalum was approximately twice that from an identical sample mounted on the original tantalum foil. An indication of the effect of sample thickness on backscattering is that the absorption curve doesn't deviate from a straight line until absorbers thinner than 0.50 mg/cm² are used. If a carefully standardized technique is employed to give accurately reproducible samples, it is possible to determine an average backscattering correction for use with this specific technique.

Low-Geometry Factors

Arrangement		
Number of holes	*Support*	$1/G$, *(Geometry factor)*$^{-1}$
4	high	$4.1376 \times 10^{3} \pm 0.08\%$
1	high	$4.0258 \times 10^{3} \pm 0.10\%$
4	low	$1.5836 \times 10^{5} \pm 0.06\%$
1	low	$1.6022 \times 10^{4} \pm 0.10\%$

Self-Absorption

If the sample is not ideally thin, those particles emitted in a direction nearly parallel to the plane of the sample will be absorbed in the sample. If a thick sample is used in absolute alpha counting, a correction must be made. The absorption curve of a sample is a straight line; the sum of the straight-line curves of a succession of very thin layers. The counting rate due to a given layer is

$$I = n - \frac{n(t+d)}{r}$$

where n is the true counting rate of each layer, r is the range of the particles, d is the thickness of sample through which particles from that layer must pass, and t is the absorber thickness. The equation of the composite curve is

$$I = I_0 - \frac{I_0 d}{r} - \frac{I_0 s}{2r}$$

where s is the total sample thickness. If the range is known or can be determined by using a thin sample of the same emitter, $s/2$ can be computed from the absorber-thickness intercept

$$r - \frac{s}{2}$$

The absolute count, I_0, can then be determined from the counting-rate intercept

$$I_0 = \frac{I_0 s}{2r}$$

The ratio of observed to absolute counting rate gives a factor that corrects for both backscattering and absorption.

The absorption curve of a sample that is not ideally thin is illustrated in Fig. 3. A least-squares analysis of the points gives $I = 81{,}898 + 13{,}412\,t$, with intercepts $81{,}898 \pm 71$ and 6.106 ± 0.030. Using 6.23 mg/cm² as the range of Po^{210} alpha-rays in aluminum, as determined with an ideal sample, $s/2$ must equal 0.124 and $I_0 = 83{,}561$ cpm, or 1.671×10^{5} dpm.

Standard Low-Geometry Chamber

For assay of high-level alpha activity (2×10^{5}–5×10^{9} dpm), low-geometry counters are used. These consist of a low-geometry attachment (*9*, *10*) and a proportional alpha counter.

The accuracy of assay depends mainly upon the certainty with which the geometry is known. Backscattered radiation cannot penetrate the mica window of the counting chamber. Sample thickness is not critical, (within limits) since only particles emitted at nearly right angles to the sample plane are counted.

Dimensions influencing absolute accuracy of the chamber were defined with limits demanded by the desired over-all accuracy. With these dimensions and tolerances established, the essential components of the geometry-defining chamber were designed in a manner that would permit construction and measurement of these components to required precision.

The chamber is shown in Fig. 4, diagram of several important parts is shown in Fig. 5. A unique feature of the standard chamber is the use of parallel-plane and coaxial-cylindrical forms that can be assembled repeatedly without change of critical dimensions.

Formation and measurement of the geometry-defining holes is most critical. These were made in 0.005-in.-thick, 17-7 PH, full-hard stainless steel: first, by perforation in a hardened, ground, and lapped perforating die with the desired hole spacing; and second, by hand lapping with fine diamond abrasive charged in brass laps, the orifice plate being held rigid in a supporting jig.

Surface-to-surface joints and O-ring

seals rather than tapered joints are used in the stainless-steel cylinder and plug. The sample slide is supported by a spring-loaded platform, so that the top of the slide is at a fixed distance from the orifice plane, regardless of the thickness of the slide material.

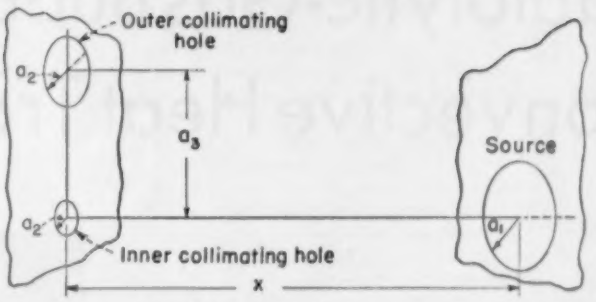
Hole diameters and spacings were measured on a Bausch and Lomb shop microscope. Sample-to-orifice-plane distance is the difference between body height (from orifice plane to locating shoulder) and plug height (from locating shoulder to upper surface of sample slide). These distances were measured on a granite surface plate, using a 0.0001-in. dial indicator and Class B gage blocks. These dimensions were measured for each combination of high and low plug. The measurements were repeated a number of times and a standard deviation computed for each combination.

The sample needed to be a ¼-in.-diameter circular source centered on a 1-in.-square slide. This specification was met by marking a circle of that size with a wax pencil on the slide and mounting inside the mark. The wax prevented the solution from spreading, as was verified with autoradiographs. If samples that differ appreciably from this size are used, a correction should be applied. In low-plug position this is 1% for ½-in. sample diameter.

The ratio of C, the number of alphas per minute that pass through the collimating holes, to I_0, the number of disintegrations emitted by the sample, is defined as G, the geometry factor. A general expression for the geometry factor is given with the diagram of low geometry on this page.

The geometry factor was calculated for each orifice. Deviations in dimensions were propagated to determine the net deviation in geometry factor. When the chamber is used with four holes open, the geometry factor is the sum of the factors for each; when used with the center hole open and the outer ones closed, the geometry factor is that for the center hole. Calculated geometry factors are tabulated in the table on p. 40; they are precise to within 0.1%.

Equation for Geometry Factor



Here is the equation that determines the geometry factor, G, in well-collimated low-geometry chamber schematized above:

$$\frac{C}{I_0} = G = \frac{a_2^2}{4x^2}\left[1 - \left(\frac{3}{4x^2}\right)(a_1^2 + a_2^2 + 2a_3^2) + \left(\frac{(3)(5)}{(2^2)(3!)x^4}\right)(a_3^4 + a_1^4 + 3a_3^4 + 6a_2^2a_3^2 + 6a_1^2a_3^2 + 3a_1^2a_2^2) - \left(\frac{(3)(5)(7)}{(2^3)(4!)x^6}\right)(a_2^6 + a_1^6 + 4a_3^6 + 6a_2^4a_3^2 + 12a_2^4a_3^2 + 6a_1^4a_2^2 + 12a_1^4a_3^2 + 18a_2^4a_3^2 + 18a_2^4a_1^2 + 36a_1^2a_2^2a_3^2) + \cdots\right]$$

For the inner aperture, where the sample and aperture are coaxial, a_3 becomes zero and the formula can be greatly simplified. If the source can be considered a point source, a_1 becomes zero and further simplification is possible.

How Accuracy Was Checked

We checked the absolute accuracy of alpha counting using both low-geometry counters and 2π counters. One indication of absolute precision with low-geometry alpha counters was the agreement in sample strengths determined in all four counting positions in the standard chamber. An error in one of the dimensions used in calibration would influence each geometry factor to a different degree. The average deviation of results from any one of the four positions to the others did not exceed 0.14% for the 5 samples used in this test. Therefore the precision must be good.

A second check was counting samples in the low-geometry chamber and then, by the absorption method, in the 2π counter. The samples used were necessarily at the lower limit of the low-geometry-alpha-counter range and at the upper limit of the 2π-counter range. In spite of this, low-geometry alpha counts averaged only 0.06% lower than 2π-counter results for the 6 samples used.

A third check was made by counting 36 mounts from dilutions of a solution that had been standardized by calorimetry. These were counted routinely in low-geometry alpha counters that had been calibrated to agree with the standard chamber. Mounts made with three different pipettes averaged only 0.17% higher than those obtained with the calorimeter.

These tests indicate that a high degree of absolute accuracy has been achieved with both 2π-geometry and low-geometry alpha counters.

* * *

Mound Laboratory is operated by Monsanto Chemical Company for the United States Atomic Energy Commission under Contract Number AT-33-1-GEN-53.

BIBLIOGRAPHY

1. M. L. Curtis, J. W. Heyd. Absolute alpha counting I: determination of backscattering factors and ranges, MLM-834 (1953). This and (2) are the original version of this article
2. M. L. Curtis, R. G. Olt, J. F. Eichelberger, Absolute alpha counting II: Standard low-geometry chamber, MLM-843 (1953)
3. L. B. Gnagey. A windowless proportional chamber for absorption measurements, MLM-857 (1953)
4. W. H. Baker. Counting Systems for Pulses of Wide Dynamic Range, MLM-618 (1953)
5. W. H. Baker. A Nonlinear Pulse Amplifier of Wide Dynamic Range MLM-851 (1953)
6. J. S. Stanton, J. W. Heyd. The Preparation of Plastic and Metallic Absorbers, MLM-858 (1953)
7. W. H. Baker, L. B. Gnagey, J. W. Heyd, J. S. Stanton, NUCLEONICS **13**, No. 2, 40, (1955)
8. H. A. Bethe, BNL-T-7 (1949)
9. S. De Benedetti, J. W. Heyd, C. Pittenger, L. Powers, C. Brenneman, and M. L. Curtis. Low-geometry attachment for methane flow proportional alpha counter, MLM-M270 (1947)
10. L. B. Gnagey. Low-geometry attachment for methane flow proportional counter (supplement), MLM-287 (1948).

Radiolytic-Gas Bubbling Improves Convective Heat Transfer in Supo

Agitation from radiolytic-gas bubbles is the main cause of 150% higher heat-transfer coefficient than predicted by theory, in the water-boiler reactor. Effects of thermal-boundary-layer heat generation and tube-wall gamma heating are also analyzed

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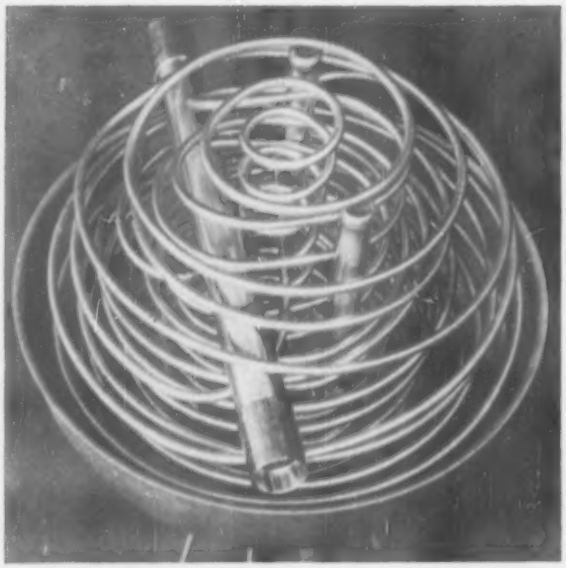

FIG. 1. Heat exchanger of Supo reactor consists of three 20-ft lengths of stainless-steel tubing, ¼-in. o. d. by 3/16-in. i. d. Tubing is coiled inside the 1-ft diameter stainless-steel sphere that comprises the reactor core. The sphere holds the reactor-fuel solution

OVER-ALL HEAT-TRANSFER COEFFICIENTS for the cooling system of Supo, as measured from nonboiling operating conditions, are much greater than those predicted for such a heat exchanger based on classical free-convection heat-transfer theory. Supo is the Los Alamos water-boiler reactor, redesigned for higher power. Figure 1 shows the heat exchanger and reactor assembly (*1*, *2*). There are several factors that might cause this increase in heat-transfer coefficient. Among these are: increased thermal convection outside the heat-exchanger tubes caused by fluid agitation from radiolytic-gas-bubble evolution; nuclear-heat generation in the thermal-boundary layer surrounding the tubes; and gamma-ray energy absorbed in the tube walls. Calculations have shown the effect of gamma-ray heating to be negligible, as indicated on p. 45 and it will not be discussed further.

Experimental heat-transfer data and order-of-magnitude analyses of the effect on heat-transfer coefficient of fluid agitation caused by bubble evolution are given. The effect of heat generation in the thermal-boundary layer is also analyzed.

Heat-Transfer Data

Water-boiler experimental data shown in the table, p. 43, covering the range of 3–40-kw reactor power, were used to determine the over-all heat-transfer coefficient for the heat exchanger from the relation

$$U_o = \frac{wc_p(T_{w2} - T_{w1})}{A_o(\Delta T)_m} \qquad (1)$$

where

$$(\Delta T)_m = \frac{(T_s - T_{w1}) - (T_s - T_{w2})}{\ln \dfrac{T_s - T_{w1}}{T_s - T_{w2}}} \qquad (2)$$

The system properties are given in the list of symbols, next page.

Experimental coefficients as determined from Eq. 1 are shown in Fig. 2 as a function of the heat flow into the exchanger, which is roughly proportional to reactor power. The data fall into three groups: (*A*), 1950 data when the reactor had not run at power for an appreciable length of time; (*B*), 1952 data after the reactor had run at power for a considerable length of time; (*C*), 1952 data after cleaning the inside of the heat-exchanger tubes with a nitric acid solution.

It is seen that the group *B* data fall considerably below the group *A* data.

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SYMBOLS AND UNITS USED

A = area, ft²
A_i = tube inside area, ft²
A_o = tube outside area, ft²
c_p = specific heat at constant pressure, Btu/lb/°F
C = constant
C_1 = constant defined by Eq. 19
D_i = tube inside diameter, ft
D_o = tube outside diameter, ft
$E(r)$ = nuclear heat per unit volume in reactor, Btu/ft³/hr
g = acceleration due to gravity, ft/hr²
G = mass flow density, lb/ft²/hr
h = convective heat-transfer coefficient, Btu/hr/ft²/°F
h_{fg} = latent heat of water, Btu/lb
h_i = tube inside convection coefficient, Btu/hr/ft²/°F
h_n = tube outside convection coefficient including nuclear heat, Btu/hr/ft²/°F
h_{ot} = tube outside convection coefficient (theoretical), Btu/hr/ft²/°F
h_{oe} = tube outside convection coefficient (experimental), Btu/hr/ft²/°F
$I(r)$ = gamma-ray heating per unit volume in tube wall, Btu/ft³/thr
k = thermal conductivity, Btu/hr/ft/°F
L = tube length, ft
P = reactor power, kw
q_i = heat-transfer rate across tube inside surface, Btu/hr
q_o = heat-transfer rate across tube outside surface, Btu/hr
q_γ = tube wall gamma-ray heating rate, Btu/hr
q_l = heat-transfer rate per unit length of tube, Btu/hr
r = radius, ft
r_i = tube inside radius, ft
r_o = tube outside radius, ft
R = tube-wall thermal resistance, (Btu/hr/ft²/°F)⁻¹
T_i = tube inside surface temperature, °F
T_o = tube outside surface temperature, °F
T_s = reactor-solution temperature, °F
T_w = average cooling-water temperature, °F
T_{w1} = inlet cooling-water temperature, °F
T_{w2} = outlet cooling-water temperature, °F
ΔT = temperature difference, fluid to wall, °F
$(\Delta T)_m$ = log-mean temperature difference, °F
U_i = inside over-all heat-transfer coefficient, Btu/hr/ft²/°F
U_o = outside over-all heat-transfer coefficient, Btu/hr/ft²/°F
$U_{i\gamma}$ = inside over-all heat-transfer coefficient including gamma heating, Btu/hr/ft²/°F
v = volume rate of bubble evolution, ft³/hr
w = mass rate of cooling-water flow, lb/hr
β = coefficient of thermal expansion, °F⁻¹
δ = thermal-boundary-layer thickness
μ = viscosity, lb_{mass}/hr/ft
ρ = density, lb_{mass}/ft³

System Properties

A_o = 3.74
c_p = 1.00*
k = 0.354,* 0.385,† 9.6‡
ρ = 62.0,* 60.6†
β = 0.0002†
μ = 1.66,* 0.84†

* = cooling solutions; † = reactor solution; ‡ = stainless steel.

This decrease in heat-transfer coefficient is attributed to scale formation inside the tubes that increases the tube-wall thermal resistance. After the tubes were cleaned, the heat-transfer coefficient increased to a value about halfway between the group A and group B coefficients. It is believed that the heat-transfer coefficient did not return to the original values because the scale formation was not entirely removed by the rather mild cleaning operation (4M HNO_3 for 12 hr). Scale or deposits on the outside of the tube is improbable. In any case, the decrease in heat-transfer coefficient of the group B and group C data is attributed to increased tube-wall thermal resistance.

The over-all heat-transfer coefficient, U_o, based on combined conduction and convection is given by

$$U_o = \left(\frac{1}{h_{oe}} + \frac{r_o \ln r_o/r_i}{k} + \frac{r_o}{r_i h_i} \right)^{-1} \quad (3)$$

Thermal resistance of the stainless-steel tube walls, based on the outside area, is $R_A = (r_o \ln r_o/r_i)/k = 3.55 \times 10^{-4}$. This resistance is assumed to apply to the group A data. The additional resistance necessary to lower the group A data to coincide with the group B data is $\Delta R_B = 7.05 \times 10^{-4}$. The additional resistance necessary to lower the group A data to coincide with the group C data is $\Delta R_C = 3.85 \times 10^{-4}$.

The tube-wall thermal resistances for group B and group C data were therefore taken as $R_B = 10.6 \times 10^{-4}$, and $R_C = 7.4 \times 10^{-4}$.

Heat-transfer coefficients inside the cooling tubes were calculated from the accepted forced-convection relation (*3*)

$$\frac{h_i D_i}{k} = 0.023 \left(\frac{D_i G}{\mu} \right)^{0.8} \left(\frac{c_p \mu}{k} \right)^{0.4} \quad (4)$$

Internal forced-convection heat-transfer coefficients from Eq. 4, experimental over-all heat-transfer coefficients from Fig. 2, and the appropriate tube-wall resistances were used in Eq. 3 to obtain values for the experimental convection coefficient outside the tubes. These values are plotted vs reactor power in Fig. 3. Also shown in Fig. 3 are values for the theoretical free-convection coefficient outside the tubes, based on the accepted relation (*3*)

Heat-Transfer Data for Supo

Group	P	T_s	T_{w1}	T_{w2}	w
A	3.85	144.7	64.4	100.2	355
A	5.76	140.2	68.9	124.2	275
A	11.6	141.4	59.0	124.2	573
A	17.15	145.6	64.0	121.3	980
A	23.1	150.3	65.8	113.9	1,565
A	25.8	158.0	64.0	122.7	1,435
B	38.6	194.4	52.7	137.3	1,415
B	30.8	178.9	56.3	124.7	1,410
B	25.2	161.6	55.0	109.8	1,420
C	40.0	189.7	63.7	141.8	1,575
C	30.4	169.2	63.1	123.1	1,580
C	38.0	185.9	63.7	135.2	1,615
C	31.3	173.8	63.5	125.2	1,570
C	37.3	183.2	62.1	134.4	1,590
B	3.2	87.8	64.9	73.6	1,345
B	3.8	160.7	54.9	138.6	105
B	38.9	194.9	50.9	135.5	1,410
B	31.6	178.7	54.5	126.5	1,370
B	36.6	191.3	54.5	135.5	1,395
B	31.2	179.6	54.4	124.0	1,390
—	39.2	193.1	55.4	138.0	1,450
—	25.3	163.8	53.6	110.3	1,405
—	25.2	170.6	64.4	118.9	1,445
—	31.0	186.1	63.9	132.1	1,390
—	31.3	186.4	63.3	132.3	1,390
—	32.0	186.1	61.3	133.7	1,390

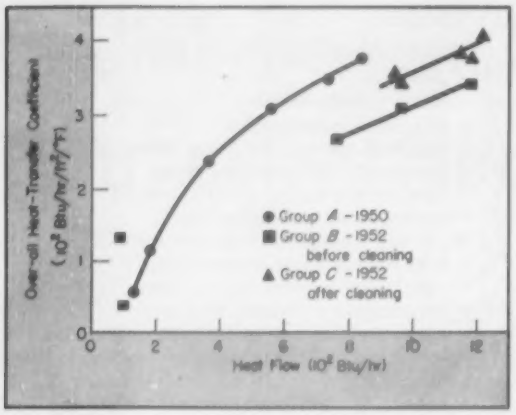
Over-all Heat-Transfer Coefficient (10³ Btu/hr/ft²/°F)
Heat Flow (10² Btu/hr)
Group A - 1950
Group B - 1952 before cleaning
Group C - 1952 after cleaning

FIG. 2. Variation of over-all heat-transfer coefficient with heat flux shows effects of scaling and partial cleaning of inside of cooling coils

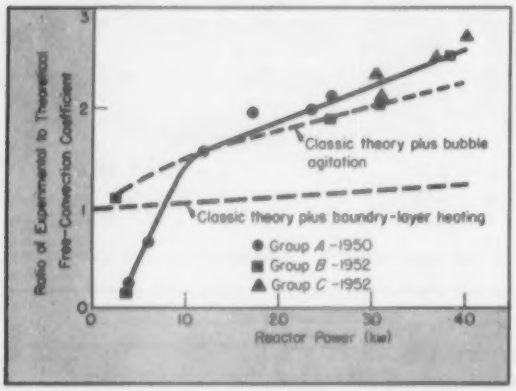
Ratio of Experimental to Theoretical Free-Convection Coefficient
Classic theory plus bubble agitation
Classic theory plus boundry-layer heating
Group A -1950
Group B -1952
Group C -1952
Reactor Power (kw)

FIG. 4. Adding effect of radiolytic-bubble agitation to conventional free-convection theory brings theoretical heat-transfer coefficient into reasonable agreement with experimental data. Lowest line is ratio, adding effect of boundary-layer heating. Solid line is from ordinary theory only

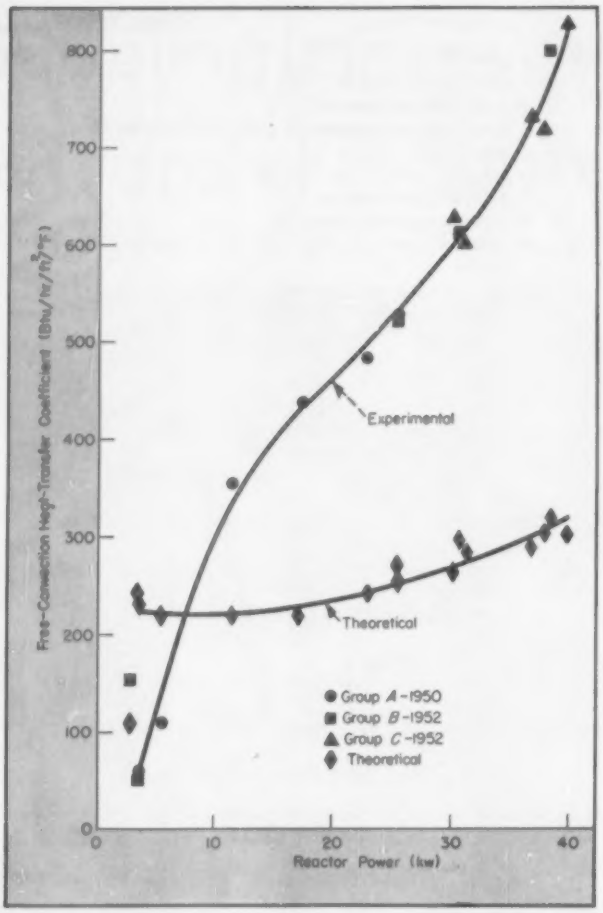

FIG. 3. Experimental free-convection heat-transfer coefficient outside the cooling coils shows large variation from the theoretical value, increasing with reactor power. Experimental value was calculated from observed heat-transfer data, calculated inside-convection coefficients, and tube-wall resistances

$$\frac{h_{ot}D_o}{k} = 0.53\left[\frac{D_o^3\rho^2 g\beta\Delta T}{\mu^2}\left(\frac{c_p\mu}{k}\right)\right]^{0.25} \quad (5)$$

As shown in Fig. 3, the theoretical free-convection coefficient is considerably less than the experimental convection coefficient for all but the very low power region. Figure 4 shows the ratio of experimental to theoretical free-convection coefficient plotted vs reactor power. Above 12 kw the increase in heat-transfer coefficient appears to be linear and satisfies

$$h_{oe}/h_{ot} = 0.0358P + 1.15 \quad (6)$$

Radiolytic-Gas Bubbles

One possible explanation for increasing heat-transfer coefficient with increasing reactor power is greater fluid agitation caused by evolution of hydrogen and oxygen bubbles in the fuel solution. Radiolytic-gas production rate is 11 l/min at 25-kw power. The rate is proportional to reactor power (*4*). It is believed that fluid agitation due to bubbles increases convection heat-transfer coefficients although rather meager experimental data are available on this phenomenon. Results of the following analysis show reasonable agreement with experimental data.

Most available data refer to boiling experiments where increased heat-transfer rates produce a higher bubble-formation rate. A particular case has been presented for boiling water on a vertical surface (*3*). When the fluid was mechanically agitated, the heat-transfer coefficient was constant and independent of heat-transfer rate. When the fluid was not stirred, the heat-transfer coefficient increased with increasing heat transfer according to

$$h = (C\Delta T)^{0.25} \quad (7)$$

Heat-transfer coefficient approached the coefficient obtained from mechanical agitation with increasing heat-transfer rate and hence increasing bubble formation. This increase was attributed to increased agitation.

For a boiling liquid the volume rate of vapor-bubble formation is related to the heat-transfer coefficient by

$$q = hA\Delta T = \rho v h_{fg} \quad (8)$$

from which

$$h = \frac{\rho v h_{fg}}{A\Delta T} \quad (9)$$

Eliminating the temperature difference between Eqs. 7 and 9 gives

$$h = \left(\frac{C\rho v h_{fg}}{A}\right)^{0.275} \tag{10}$$

The change in heat-transfer coefficient for a change in bubble-volume formation is then found from

$$\frac{h}{h_r} = \left(\frac{v}{v_r}\right)^{0.275} \tag{11}$$

where h_r and v_r are arbitrary corresponding reference values.

Equation 11 was applied to the water-boiler experimental data using the elbow in Fig. 4 as the reference value. The resulting curve is shown as the upper dotted line in Fig. 4, which is in reasonable agreement with the experimental data from 12–40 kw.

Other boiling-heat-transfer data from McAdams (*3*) when treated in the above manner would yield an exponent larger than the 0.275 given by Eq. 11. It is interesting to note that an exponent of 0.4 would give excellent agreement for the range covered. The data on which Eq. 7 is based were chosen for the above development since the reference experiment with boiling water gave a comparison with data obtained by mechanical agitation.

Other correlations. Several types of fundamental generalized analyses have been attempted with the water-boiler data with the hope of establishing a significant heat-transfer correlation that would apply to higher reactor-power levels than those reported. However, the data are insufficient in range and accuracy to prove one concept over another and the details of these analyses are not presented.

The increase in heat-transfer coefficient with bubble evolution is undoubtedly caused by increased local velocities around the heat-exchanger tubes. If the relation between the radiolytic-gas volume rate and the local velocities were known, a standard forced-convection heat-transfer correlation relating the Nusselt number to the Reynolds and Prandtl numbers could probably be used to predict heat-transfer coefficients directly in terms of volume rate. It would be expected that such a correlation could be reduced to the form of Eq. 11 based on known reference values of heat-transfer coefficient and volume rate.

Low-power convection coefficient. A probable explanation for the rapid

Effect of Gamma-Ray Heating

The effect on heat-transfer coefficient of gamma-ray heating of the cooling-coil walls was investigated, and found negligible, in the manner:

The steady-state heat balance on the heat-exchanger tubes is $q_o + q_\gamma = q_i$. Substituting terms, $h_{ot}A_o(T_s - T_o) + q_\gamma = h_iA_i(T_i - T_w)$. Heat flow out of the tube by conduction at the surface, $r = r_i$, is

$$q_i = kA_i(dT/dr)_{r=r_i} \tag{17}$$

For a cylindrical geometry (*8*)

$$(dT/dr)_{r=r_i} = C_i/r_i \tag{18}$$

where

$$C_i = \left(T_o - T_i + \frac{1}{k}Z\right) \Big/ (\ln r_o/r_i) \tag{19}$$

and

$$Z = \int_{r_i}^{r_o} \frac{\int_{r_i}^{r} I(r) r dr}{r}\, dr \tag{20}$$

Combining Eqs. 17, 18, and 19

$$T_o - T_i = \frac{r_i q_i}{kA_i} \ln \frac{r_o}{r_i} - \frac{Z}{k} \tag{21}$$

Convection at the inner tube surface gives

$$T_i - T_w = q_i/h_iA_i \tag{22}$$

Convection at the outer tube surface and the steady-state heat balance give

$$T_s - T_o = (q_i - q_\gamma)/h_{ot}A_o \tag{23}$$

Adding Eqs. 21–23 gives

$$T_s - T_w = q_i\left(\frac{1}{h_iA_i} + \frac{r_i \ln r_o/r_i}{kA_i} + \frac{1}{h_{ot}A_o}\right) - \frac{Z}{k} - \frac{q_\gamma}{h_{ot}A_o} \tag{24}$$

If the gamma-ray heating per unit volume is considered uniform through the tube wall, which is approximately true for a thin-walled tube, then

$$Z = \frac{I}{2}\left(\frac{r_o^2 - r_i^2}{2} - r_i^2 \ln r_o/r_i\right) \tag{25}$$

and

$$q_\gamma/A_o = (I/2r_o)(r_o^2 - r_i^2) \tag{26}$$

Combining Eqs. 24–26 results in

$$q_i = U_iA_i\left[(T_s - T_w) + \frac{I(r_o^2 - r_i^2)}{2}\left(\frac{1}{r_oh_{ot}} + \frac{1}{2k}\right) - \frac{Ir_i^2 \ln r_o/r_i}{2k}\right] \tag{27}$$

where U_i is the conventional over-all coefficient.

Now define an over-all heat-transfer coefficient including gamma heating

$$U_{i\gamma} = q_i/A_i(T_s - T_w) \tag{28}$$

Eliminating q_i between Eqs. 27 and 28 gives

$$\frac{U_{i\gamma}}{U_i} = 1 + \frac{I}{2(T_s - T_w)}\left[(r_o^2 - r_i^2)\frac{r_oh_{ot} + 2k}{2kr_oh_{ot}} - \frac{r_i^2 \ln r_o/r_i}{k}\right] \tag{29}$$

Evaluation of Eq. 29 for the maximum-power water-boiler data resulted in a value of 1.001. The average gamma-ray heating in the tube wall was taken as 3×10^4 Btu/hr/ft^3, based on a total gamma-ray source strength of 5.0% of the total reactor power, and an absorption coefficient of 0.737/in. in the stainless-steel tubes. This calculation thus shows the effect on heat-transfer coefficient of gamma-ray heating in the tube walls is negligible.

increase in the experimental coefficient in the low-power range and the initial low values shown in Fig. 4 is that initially many of the radiolytic-gas bubbles form on and cling to the cooling tubes, thus insulating them from the solution. With increased gas generation, the increased agitation sweeps more and more of the clinging bubbles from the tubes with a corresponding rapid increase in heat-transfer coefficient.

Another possible reason for the increase in heat-transfer coefficient with increasing reactor power is the nuclear heat generation in the thermal-boundary layer surrounding the tubes. This effect is not present in ordinary free-convection problems.

Boundary-Layer Heating

The thermal-boundary layer is defined as the fluid region adjacent to the tube wherein exists a temperature gradient in a direction normal to the tube surface. The following analysis was performed to determine the order-of-magnitude effect of heat generation within the boundary layer.

Assume that the heat transfer through the convection film is equal to that normally calculated for free convection plus the nuclear energy generated in the thermal-boundary layer. For the outside of a tube

$$q_l = 2\pi L \int_{r_o}^{r_o+\delta} E(r) r dr + 2\pi L r_o h_{ot}(T_s - T_o) \quad (12)$$

The total outside coefficient can now be defined from

$$q_l = 2\pi L r_o h_n (T_s - T_o) \quad (13)$$

For uniform energy generation per unit volume, Eq. 12 can be integrated. From this result and Eq. 13, the total coefficient is then

$$h_n = \frac{E\delta}{T_s - T_o}\left(1 + \frac{\delta}{D_o}\right) + h_{ot} \quad (14)$$

from which

$$\frac{h_n}{h_{ot}} = \frac{E\delta}{(T_s - T_o)h_{ot}}\left(1 + \frac{\delta}{D_o}\right) + 1 \quad (15)$$

From Eq. 14, the contribution of the nuclear heating is directly proportional to the power and inversely proportional to the temperature difference across the convective film.

Thermal-boundary-layer thickness for a short vertical surface of height D_o in free convection is given by

$$\frac{\delta}{D_o} = 6.5\left[\frac{D_o^3\rho^2 g\beta\Delta T}{\mu^2}\left(\frac{\mu c_p}{k}\right)\right]^{-0.25} \quad (16)$$

which is obtained from Jakob (*5*) by introducing the fourth root of the Prandtl number.

Experimental data for horizontal cylinders in free convection to air (*6*, *7*) satisfy a relation similar to Eq. 16 except for the coefficient, which is 9.4 (*6*), or 6.75 (*7*). It is therefore believed that Eq. 16 can be used to determine approximately the thermal-boundary-layer thickness. Boundary-layer thickness is evaluated on a horizontal plane through the cylinder axis.

Equations 15 and 16 were applied to the water-boiler data with the nuclear-heat generation considered as uniform throughout the reactor. The resulting curve is shown in Fig. 4. The total outside coefficient has a maximum value of 1.2 times the theoretical coefficient, at 40 kw. The curve shown should be the effect's upper limit because:

1. Nuclear-heat generation was considered uniform, while it actually will be decreased near the tube walls.
2. Nuclear-heat generation was considered to have no effect on the thermal-boundary-layer thickness for free convection, while it probably will reduce the thickness somewhat since its effect would be to increase local convection velocities near the tube walls.
3. Any agitation of the fluid caused by bubble evolution would tend to reduce the thermal-boundary-layer thickness appreciably by increasing the local velocities near the tube walls.

Conclusion

The agreement between the experimental heat-transfer coefficients and those predicted from radiolytic gas bubble evolution is probably fortuitous, since the geometry and mechanism of bubble formation upon which the predictions were based were dissimilar to those of the water boiler. However, this agreement, combined with the relative insignificance of thermal-boundary-layer heat generation tends to substantiate the conclusion that the primary cause of the high heat-transfer coefficients is fluid agitation resulting from radiolytic-gas-bubble evolution.

* * *

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BIBLIOGRAPHY

1. H. S. Isbin, NUCLEONICS, **11**, No. 6, 65 (1953)
2. L. D. P. King, AECD-3287 (1951)
3. W. H. McAdams, "Heat Transmission" pp. 168, 244, 313. (McGraw-Hill Book Co., Inc., New York, 1942)
4. L. D. P. King, R. P. Hammond, J. A. Leary, W. R. Wykoff, NUCLEONICS **11**, No. 9, 25 (1953)
5. M. Jakob, "Heat Transfer" pp. 447–449 (John Wiley and Sons, Inc., New York, 1949)
6. R. B. Ray, *Proc. Indian Assoc. Cultivation Sci.* **5**, 1920 (1922)
7. R. B. Kennard, *Bur. Standards J. Research* **5**, 11952 (1930)
8. F. P. Durham, *Am. Soc. Mech. Engrs. paper* 54-A-126 (1954)

Power Reactor Package (continued from page 24)

ment work and fuel elements,* the plant would cost about $1,703,000. Itemized, this is: reactor, $148,000; primary coolant system, $357,000; steam system, $171,000; main condenser cooling system, $61,500; evaporator system, $22,000; primary coolant water purification system, $32,000; pressurizer system, $40,500; reactor instruments and controls, $82,000; process instruments and controls, $38,500; electrical systems, $82,000; building (including crane, platforms, and ventilating equipment), $260,000; 500 yd³ of concrete for shielding, $70,500; miscellaneous, $42,000; 10% for contingencies, $140,700; 10% for engineering, $155,300.

Installed plant costs/kw. The reactor will produce 1 Mw net electric power and 12.1×10^6 Btu/hr (3,535 Mw) steam for heating purposes. Analysis of plant costs indicates that 45% should be charged to steam and 55% to electric power. This gives installed plant costs of $936/kw net electricity and $216/kw steam heat.

Kilowatt-hour costs. When the reactor operates at an average of 60% of full load, total costs in mills/kwh for net steam and electricity are estimated to be 53.30 for the electricity and 12.34 for the steam. Capital costs are 27.82 and 6.44, and operating costs are 25.48 and 5.90 mills/kwh, respectively. Capital costs include fixed plant and fuel-inventory charges; operating costs include labor, maintenance, and costs for fuel fabrication, burnup, and chemical reprocessing. The optimum refueling cycle was determined from Fig. 6.

* In requesting bids on the APPR, AEC said that if the contractor wishes, the Commission would supply fuel elements and control rods at a fabrication cost of $140,000 (NU, Oct. '54, p. 24).

Using Neutrons for Remote Liquid-Level Gaging

First tests of liquid-level measurement using a fast-neutron source and a new slow-neutron detector show that method works well for hydrogenous and other light liquids. Less shielding is needed than with a gamma gage; advantage of completely external measuring is retained. Accuracy of new method is ± 2 mm

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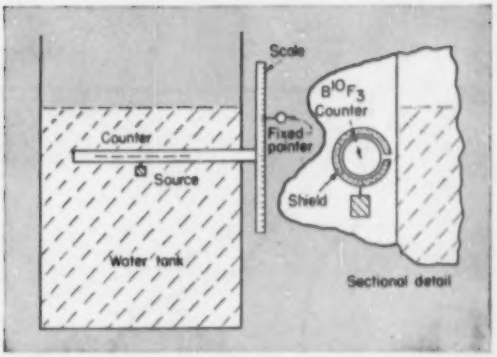

FIG. 1. Experimental set-up for determining liquid-level by neutron radiation uses rectangular brass tank, 30-cm square by 50-cm high, and movable counter with neutron source attached. Inset shows shield for $B^{10}F_3$ counter, consisting of two concentric Cd tubes, each 0.4-mm thick, filled with 2.5-mm of boron carbide

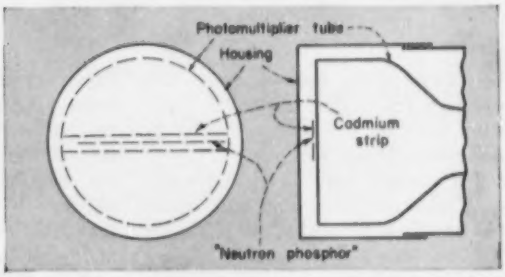

FIG. 2. Slow-neutron detector is made of "neutron-phosphor" strip placed against face of DuMont type K 1198 photomultiplier tube. Neutron phosphor is made by embedding silver-activated zinc sulfide particles in glyceryl-borate polyester. Strip is 11-cm long by 0.15-cm wide by 0.12-cm thick. Cadmium sheet 1.2-cm wide and 0.12-cm thick surrounds phosphor. Entire assembly is encased in light-tight aluminum housing

THE FEASIBILITY OF USING neutron radiation in a remote liquid-level gage is the subject of this article. The equipment used for the study and results for different geometries are explained. Measuring liquid level in a container by nuclear radiation depends on the fact that radiation is transmitted with less loss through gas than through liquid, or on the fact that back-scattering occurs to a greater degree in liquid. Several level gages based on differential transmission of gamma rays have been described (*1–8*). Other gages utilize back-scattering of γ-rays (*1, 9, 10*). However, the paucity of actual data published prevents comparing the precision of the various γ-ray devices.

Using neutron radiation for measuring liquid level has received much less attention than using γ-radiation, although neutron gaging appears to be more attractive because less and consequently lighter shielding is required. Neutron gaging is especially attractive for liquids containing hydrogen or other low-atomic-weight elements, since collisions with these elements quickly slow down neutrons, and slow neutrons can be detected much more efficiently than fast ones. Thus a convenient remote liquid-level gage can be made by placing a fast-neutron source near a slow-neutron counter, and moving the assembly vertically just outside the liquid container. The fast neutrons that enter the liquid are slowed down, and some of them are scattered back and detected by the counter. As the detector is moved from just above the liquid level to just below it, a sudden increase in count is obtained. This method of determining level was suggested in 1945 by Hare (*11*), although no data have appeared to indicate what positioning of source and counter is most effective or how accurately the level may be measured. These factors were investigated in the following experiments. The results indicate that the neutron-radiation method may be suitable for practical applications.

How Experiment Was Done

Essential parts of the apparatus used in this study are shown schematically in Fig. 1. The liquid (tap water) was in a rectangular brass tank with 0.16-cm walls. The source was in a nickel tube 2.5-cm long × 0.6-cm diameter. It produced 8×10^5 fast neutrons/sec from 400 mc of polonium with

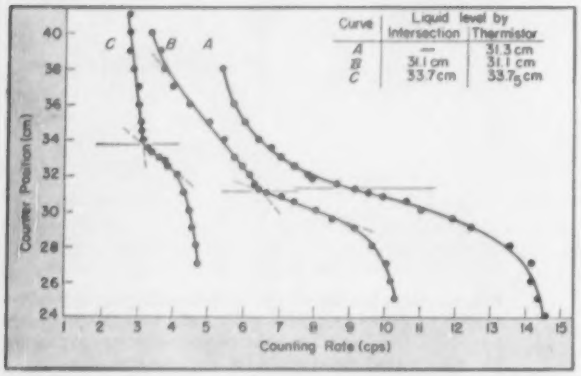

FIG. 3. Source moves with detector, at fixed distance below detector. Distances below are as follows: for curve A-2.0 cm; for curve B-6.2 cm; for curve C-10.8 cm

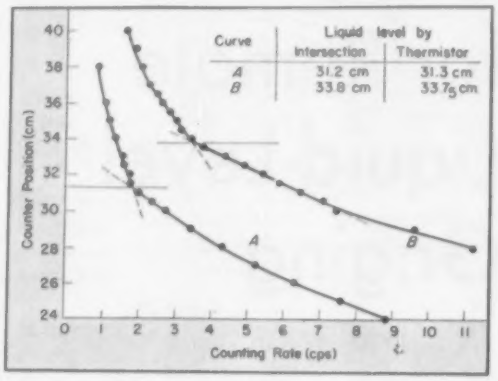

FIG. 4. Source is stationary 15-cm below liquid level as detector moves. Higher counting rates for B are caused by block of paraffin wax 6-cm thick covering source

beryllium. Safe distance from this source is 56 cm for continuous exposure, based on a maximum dose of 20 fast neutrons/cm²/sec.

The counter could be moved vertically just outside the tank wall, carrying a centimeter scale. As the scale traveled past a fixed pointer, counter position was indicated to ±0.2 mm.

Two types of neutron counters used. One type of neutron counter used was a boron trifluoride counter 2.5 cm in diameter containing $B^{10}F_3$ gas, at 40-cm Hg. The effective counting surface was a horizontal slot 15-cm long × 0.2-cm wide. As indicated in Fig. 1, the remaining area of the counter tube was covered with a shield that absorbed thermal neutrons and provided some collimation of the neutrons diffusing through the tank wall to the counter. Electrical pulses from the counter were fed into and recorded by a Tracerlab Ampliscaler. This counter was used in all experiments except where otherwise noted.

The other counter used was the scintillation counter depicted in Fig. 2. The detecting element was a "neutron phosphor" made by embedding silver-activated zinc sulfide particles in a glyceryl-borate polyester containing naturally occurring boron (*12*). This counter will be described in detail in a future issue of NUCLEONICS. The neutron phosphor was placed horizontally against the face of a photomultiplier tube. Photomultiplier tube output was fed into a cathode follower, linear amplifier, discriminator and scaler. Although the active area of the scintillation counter was about half that of the boron-trifluoride counter, the scintillation counter was more efficient—it yielded more than double the count of the boron-trifluoride counter under comparable conditions.

Liquid-level measurements. An independent liquid-level measurement was obtained in each experiment by a thermistor 1 mm in diameter. This was fixed to the counter, so that the thermistor moved vertically inside the tank wall as counter position was changed. Constant voltage was applied across the thermistor. Thermistor current was relatively high in air and much lower when the thermistor was cooled by the water. Thus, as the thermistor was lowered towards the water, the position where the current suddenly decreased corresponded to the liquid level. The probable error in this measurement was estimated to be $< \pm 1$ mm.

Counting-Rate Curves

Curves of neutron counting rate vs counter position for various arrangements of source and counter are shown in Figs. 3–6. Counter position is plotted as the ordinate. The scale refers to an arbitrary zero that is very close to the bottom of the water tank. Liquid level, as determined by the thermistor, is shown as a horizontal line (the points below the line correspond to readings opposite the liquid).

There is a definite discontinuity in the curve at the water level for most of the geometries studied. In the more favorable cases, where the curve is linear on either side of the sharp break, intersection of the two lines can be fixed to ±1 mm or closer. In all these cases the liquid level as indicated by the point of intersection on the curve agreed with the thermistor determination to ±1.5 mm or better. This agreement is within experimental error.

Source below counter. Figure 3 shows data obtained when the source is moved with the counter a fixed distance below it. With the source very close to the counter (2.0-cm away, curve *A*), the counting rate increases rapidly as the counter approaches the liquid level from above, resulting in a smooth sigmoidal curve. This type of curve is an undesirable one, although the point of inflection appears to be close to the liquid level. The sharp rise in count as the water level is closely approached from above results from the fact that, when the source is just opposite the water level and is moving downward, the number of neutrons being confined by the water is increasing rapidly. When the source is placed somewhat farther below the counter (6.2-cm away, curve *B*), a discontinuity in the counting rate appears at the liquid level. With the source relatively far away (10.8 cm, curve *C*), the counting rate increases very slowly as the counter approaches the liquid from above; therefore as the water level is

position of source and detector

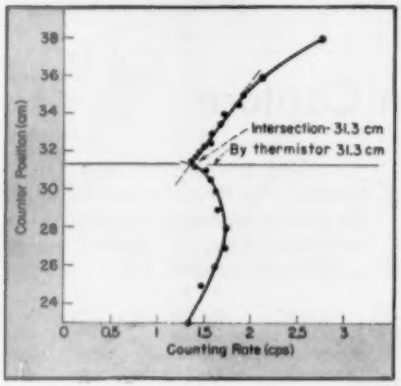

FIG. 5. Source is stationary at 15-cm above liquid level. Low rise in counting rate as detector moves past liquid level is undesirable

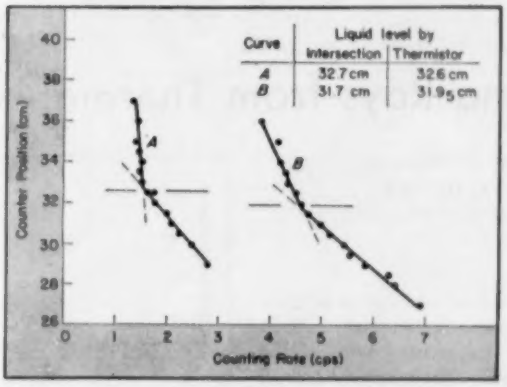

FIG. 6. For A, source was inside the liquid, stationary at 15-cm below the level. For B, source moved with detector, 8.3-cm above it. Thicker-walled tank was used

passed, the rise in count, although not as great as before, is quite sharp.

Behavior similar to that shown on curve *C* is expected if the source were to be fixed outside the tank relatively far below the water level, with the region around the level being scanned by the counter. This is confirmed by Fig. 4, curve *A*, for which the fast-neutron source was fixed to the outside of the tank 15 cm below the level. Curve *B* in this figure shows the results when a block of paraffin wax, shaped to fit symmetrically over the source, was placed against the tank, covering the source with approximately 6 cm of wax. The paraffin produced essentially a slow-neutron source of greater intensity, but otherwise the curve obtained was similar to that with the fast-neutron source. Principle advantage of converting a fast-neutron source to a slow one appears to be that less radioactive material is needed.

Since the slow neutrons in the liquid inside the tank largely determine the counting-rate curve shape, an equally sharp break at the liquid level is expected on placing the stationary source inside the liquid rather than outside of it. This was confirmed by experiment.

Source above counter. The previous results demonstrate that when the source is positioned below the counter, it should not be placed too close to it. Experiments with the source above the counter indicate that the source should not be too far away in this case. With the center of the source as close as 2.0 cm above the counting element, the counting curves showed sharp discontinuities at the liquid level and resembled those in Fig. 4. Figure 5 presents the case where the source is stationary and relatively far (15 cm) away from the liquid level—note the minimum corresponding to the liquid level. The important point demonstrated here is that the rise in counting rate as the counter passes down under the level is relatively small. This undesirable feature would be expected to occur also when the source is moved with the counter but fixed at a relatively large distance above it.

The previous results were obtained with a brass container having a wall thickness of only 0.16 cm ($\frac{1}{16}$ in.). It was expected that a thick container wall would tend to make the discontinuity in neutron count at the liquid level less sharp. There are two reasons for this: the detector does not pass as closely to the liquid-gas interface; and the neutrons are scattered within the container wall. Figure 6 presents data obtained when the tank-wall thickness was increased by placing a steel sheet 1.27-cm ($\frac{1}{2}$-in.) thick against the brass wall. The scintillation counter was used in these experiments. Curve *A* was obtained with the source inside the liquid, 15 cm below the level and 15 cm inside the tank wall. The break in the curve is sharp and indicates the level accurately. With the source 8.3 cm above the counter, curve *B* in this figure, the break in the curve is not as well defined. These examples illustrate the need for determining the best relative location of the source for a given thick-walled container. For thin-walled containers there is a rather wide choice of source locations.

Conclusions

The level of a hydrogenous liquid in a tank can be measured remotely to ±2 mm or better from outside the container by means of a fast-neutron source attached to a slow-neutron counter. The source may be positioned below but not too close to the counter, or above the counter but not too far away from it. Equal precision is attainable when the source is stationary and either opposite the liquid outside the tank or inside the liquid.

* * *

We are grateful to P. R. Malmberg for helpful advice, and to M. Giuliano and P. Szydlik for assistance with some of the measurements.

BIBLIOGRAPHY

1. D. G. C. Hare, U. S. Patent 2,323,128 (June 29, 1943)
2. L. S. McCaslin, *Oil Gas J.* **46**, No. 21, 100 (1947)
3. A. Wolf, U. S. Patent 2,456,233 (1948)
4. D. M. McCutcheon, *Am. Foundryman* **15**, No. 6, 35 (1949)
5. F. S. McCarthy, G. A. Rico, *J. Electrochem. Soc.* **97**, 249 (1950).
6. J. E. Johnston, *Brit. Cast Iron Research Assoc. J. Research and Develop.* **3**, 523 (1950)
7. R. Meakin, *J. Sci. Instr.* **28**, 372 (1951)
8. J. E. Jacobs, R. F. Wilson, *Electronics* **24**, No. 10, 172 (1951)
9. D. G. C. Hare, U. S. Patent 2,348,810 (May 16, 1944)
10. J. H. Kunkel, *Petroleum Engr.* **16**, No. 12, 155 (1945)
11. D. G. C. Hare, U. S. Patent 2,378,219 (June 12, 1945)
12. K. H. Sun, *et. al., Phys. Rev.* **98**, 600 (1954)

Gamma Rays from Thermal-Neutron Capture

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GAMMA RAYS from absorption of thermal neutrons in a reactor and its shield are often of major importance to the shield designer. Table on p. 51 lists all available data on these gamma rays in useful form. Not all elements are listed since not all have been measured.

In all cases, the target material is listed. Usually this is the natural element, but in some instances single isotopes are tabulated as indicated by the mass number following the element name. In these instances, the capture cross section applies only to the isotope indicated. Tabulated (n, γ) cross sections were usually taken from applicable papers of the Kinsey-Bartholomew-Walker group (*1–14*). If no such reference existed, the cross section was obtained from AECU-2040 (*35*).

Gamma rays emitted by an element after thermal-neutron absorption fall into two classes: "capture" and "decay" gamma rays. Capture gamma rays originate when a nucleus, having absorbed a thermal neutron, releases the binding energy of the neutron (5–10 Mev). Usually this energy is given off promptly ($\sim 10^{-14}$ sec) in the form of one or more gamma rays. "Decay" gamma rays are produced if the de-excited nucleus is still unstable, and decays by beta and gamma emission to a stable nucleus; pertinent information is tabulated in the last column.

Capture-gamma-ray spectra are tabulated by four major types. Three are illustrated by Figs. 1–3 and described in accompanying captions. A fourth "type," that for which the gamma rays are weak or nonexistent because particle emission is the favored mode of de-excitation, is necessarily not illustrated. Boron-10 and lithium-6 are the only representatives of that class included here (because of importance to shielding design).

In addition to spectral classification, the number of photons emitted in various energy intervals per 100 captures is tabulated. In some cases sufficient data were available to determine the total number of photons in each energy interval. In other cases, only the intensity of the resolved lines could be determined. For spectral types 1 and 2 the difference is small, but for type-3 spectra the difference is significant. Fortunately, sufficient data were available to determine the number of unresolved photons for most type-3 spectra. For those elements for which the number of unresolved photons has been determined, the spectral type is marked with an asterisk (*).

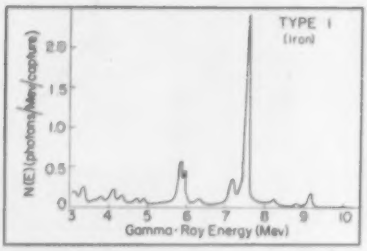

FIG. 1. Type 1 capture-gamma-ray spectrum shows few gamma rays. Ground-state-transition line dominates. Most of de-excitation energy is carried by single 6–8-Mev gamma rays

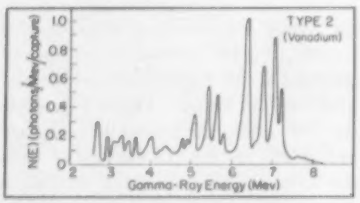

FIG. 2. Type 2 capture-gamma-ray spectrum shows many gamma rays. Distinct line structure is evident. This is typical of light and medium-weight elements with fairly large level spacing between levels and transitions between levels as likely as transitions to ground

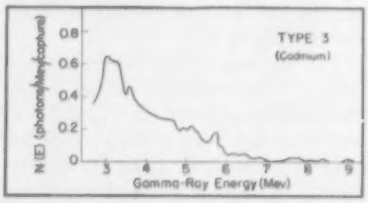

FIG. 3. Type 3 capture-gamma-ray spectrum shows many gamma rays, no line structure below 5 Mev. This is typical of heavier elements; they have high level density and overlapping highest levels. Distribution peaks below half maximum energy

* * *

This article is based largely on NDA 10-99 prepared under contract with Pratt and Whitney Aircraft Division of United Aircraft Corporation. Table has been revised and brought up to date by R. A. Liedtke under AEC contract AT(30-1)862C.

BIBLIOGRAPHY

1. B. B. Kinsey, G. A. Bartholomew, W. H. Walker, *Phys. Rev.* **82,** 380 (1950)
2. B. B. Kinsey, G. A. Bartholomew, W. H. Walker, *Phys. Rev.* **83,** 519 (1951)
3. B. B. Kinsey, G. A. Bartholomew, W. H. Walker, *Phys. Rev.* **85,** 1012 (1952)
4. B. B. Kinsey, G. A. Bartholomew, *Phys. Rev.* **89,** 375 (1953)
5. G. A. Bartholomew, B. B. Kinsey, *Phys. Rev.* **89,** 386 (1953)
6. G. A. Bartholomew, B. B. Kinsey, *Phys. Rev.* **90,** 355A (1953)
7. G. A. Bartholomew, B. B. Kinsey, *Phys. Rev.* **93,** 1434(E) (1954)
8. B. B. Kinsey, G. A. Bartholomew, W. H. Walker, *Can. J. Phys.* **29,** 1 (1951)
9. G. A. Bartholomew, B. B. Kinsey, *Can. J. Phys.* **31,** 49 (1953)
10. B. B. Kinsey, G. A. Bartholomew, *Can. J. Phys.* **31,** 537 (1953)
11. B. B. Kinsey, G. A. Bartholomew, *Can. J. Phys.* **31,** 901 (1953)
12. G. A. Bartholomew, B. B. Kinsey, *Can. J. Phys.* **31,** 927 (1953)
13. G. A. Bartholomew, B. B. Kinsey, *Can. J. Phys.* **31,** 1025 (1953)
14. B. B. Kinsey, G. A. Bartholomew, *Can. J. Phys.* **31,** 1051 (1953)
15. T. H. Braid, *Nuclear Science Abstracts,* **7,** No. 6B, New Nuclear Data (1953); *Phys. Rev.* **90,** 355A, (1953)
16. T. H. Braid, *Phys. Rev.* **91,** 442 (1953)
17. H. T. Motz, *Phys. Rev.* **90,** 355A (1953), *Nuclear Science Abstracts,* **7,** No. 6B, New Nuclear Data (1953)
18. H. T. Motz, *Phys. Rev.* **93,** 925A (1954)
19. R. W. Pringle, G. Isford, *Phys. Rev.* **83,** 467, (1951)
20. R. W. Pringle, *Phys. Rev.* **87,** 1016 (1952)
21. W. A. Reardon, R. W. Krone, R. Stump, *Phys. Rev.* **91,** 334 (1953)
22. W. A. Reardon, R. W. Krone, R. Stump, *Phys. Rev.* **91,** 442A (1953)
23. W. Thornton, et al, *Phys. Rev.* **86,** 604A (1952)
24. C. O. Muehlhause, *Phys. Rev.* **79,** 277 (1950)
25. R. E. Bell, L. G. Elliot, *Phys. Rev.* **79,** 282 (1950)
26. F. Ajzenberg, T. Lauritsen, *Revs. Mod. Phys.* **24,** 321 (1952)
27. M. Reier, M. H. Shamos, *Phys. Rev.* **95,** 636A (1954) also BNL-1667
28. A. Recksiedler, B. Hamermesh, *Phys. Rev.*, **95,** 650 (1954)
29. A. Recksiedler, B. Hamermesh, *Phys. Rev.* **96,** 109 (1954)
30. B. Hamermesh, R. J. Culp, *Phys. Rev.* **92,** 211L (1953)
31. B. Hamermesh, V. Hummel, *Phys. Rev.* **88,** 916 (1952)
32. B. Hamermesh, V. Hummel, *Phys. Rev.* **83,** 663 (1951)
33. J. M. Hollander, I. Perlman, G. T. Seaborg, *Revs. Mod. Phys.* **25,** 469 (1953)
34. P. Chudom and C. O. Muehlhause, Plutonium Project Report CP-3801, Pg. 25
35. Neutron Cross Section, AECU 2040

Target	Thermal (n,γ) cross section (barns)	Spectral type	Photons in designated (Mev) energy intervals per 100 captures					Highest energy gamma-ray (Mev)	Average number of photons/capture (24)	Fraction of energy emitted $S(E_m)$ (10)†		References	Decay gammas‡¶
			0–1	1–3	3–5	5–7	>7			E_m (Mev)	$S(E_m)$		
Aluminum	0.215	1	?	>13	77	21	35	7.724	~2	2.5	0.78	(2)	2.3-min Al^{28}: 100(1.80)
Antimony	6.4	3*	?	~80	36	12		6.80				(13)	Complicated
Arsenic	4.1	3*	?	~80	47	22	1	7.30	2.7			(13)	Complicated, uncertain
Barium	1.17	3*	?	~80	75	14	1	9.23				(14)	
Beryllium††	0.009	1	0	0	50	75	0	6.814				(9)	
Bismuth††	0.015	1	0	0	100	0	0	4.17				(1)	
Boron-10§	3,990	4	0	0	0	0	0	0.478				(26)	Fast B^{11}§: 94 (0.478)
Cadmium	3,500	3*	>120	20	73	17	1	9.046	4.1			(6, 14, 17, 20–23, 28, 29)	
Calcium	0.406	2	?	50	60	101	2.4	7.83		2.6	0.80	(3, 16)	
Carbon-12	0.0045	1	?	<30	100	0	0	4.95	1.3	3.68	0.93	(8, 9)	
Chlorine	32	2	?	20	13	18	21	8.56	3.1	3.3	0.26	(3, 15, 21, 22, 28, 29, 31)	
Chromium	2.9	1*	>37	16	12	18	69	9.716	>2	2.8	0.73	(4, 16, 27)	
Cobalt	34.8	2*	?	?	36	49	8	7.486		2.5	0.67	(5, 7, 21, 22, 27)	5.3-y Co^{60}: 100(1.17), 100(1.33)
Copper	3.59	1*	?	?	>23	22	42	7.914	2.6	3.4	0.67	(5, 7, 27)	
Fluorine	0.009	1	?	?	?	35	0	6.63				(4)	12-sec F^{20}: 100(1.63)
Gadolinium	36,300	3*	?	80	23	4	2	7.78	3.9			(14)	
Gold	94	3*	?	?	66	38	0	6.494	3.5			(13, 17)	
Hydrogen-1††	0.330	1	0	100	0	0	0	2.230				(25, 30)	
Indium	190	3*	?	?	36	4	0	5.86	3.3			(13)	54.3-min In^{116}: 18 (2.09), 15(1.49), 54(1.27), 39(1.09)
Iron	2.43	1*	?	<10	24	22	50	10.16	1.7	3.0	0.78	(4, 27, 33)	
Lead††	0.17	1	0	0	0	7	93	7.38				(1)	
Lithium-6	910	4	0	0	0	0	0	0				(26)	
Magnesium	0.059	2	?	>59	110	25	11	9.216		2.6	0.99	(2, 11, 16)	9.58-min Mg^{27}: 10(0.84), 2(1.01)
Manganese	12.6	2*	?	?	>27	30	27	7.261	2.6	3.5	0.64	(5, 7, 19, 27, 32)	2.59-hr Mn^{56}: 100(0.845), 25 (1.81), 15(2.13)
Mercury	380	3*	?	?	86	41	0	6.446	3.3			(14)	
Molybdenum	2.4	3*	?	?	84	26	3	9.15				(14)	
Nickel	4.8	1	?	?	>14	30	72	8.997		3.4	0.95	(4)	
Niobium	1.1	3*	?	?	54	14	0	7.19	2.6			(13)	
Nitrogen-14	0.1	2	?	<5	<35	90	39	10.8				(8)	
Phosphorous	0.193	2	?	?	115	43	11	7.94		2.5	0.66	(3)	
Platinum	8.1	3*	?	~120	45	15	1	7.920				(14)	Complicated
Potassium	1.89	2	?	36	36	32	12	9.28		3.00	0.48	(3, 12, 16)	
Praseodymium	11.2	3*	?	~80	34	8	0	5.83				(13)	19-hr Pr^{142}: 4(1.58)
Rhodium	150	3*	?	~70	38	10	0	6.792				(13)	Exist (34)
Samarium	10,600	3*	?	~150	45	5	1	7.89	5.6			(14)	
Scandium	22	3*	?	?	63	29	14	8.85				(5, 7)	85-d Sc^{46}: 100 (1.12), 100(0.89)
Selenium	11.8	3*	?	?	65	27	11	10.483				(14)	
Silicon	0.160	2	?	>100	229	41	16	10.55		2.5	1.44	(2, 16)	
Silver	60	3*	?	~90	70	17	0.5	7.27	2.9			(13)	Complicated 270-day Ag^{110}
Sodium	0.47	2	≈100	>50	61	29	0	6.41	<2			(2, 15, 17)	14.9-hr Na^{24}: 100 (2.758), 100(1.380)
Strontium	1.16	(2–3)*	?	~140	62	49	13	9.22				(14)	
Sulfur	0.49	2	?	>19	80	91	8	8.64		2.7	0.76	(3)	
Tantalum	21.3	3*		~50	26	2	0	6.07				(13)	Complicated
Thallium	3.3	3*	?	~100	76	62	0	6.54				(13)	
Tin	0.65	3*	?	?	139	33	4	9.35				(14)	
Titanium	5.8	2*	>50	100	33	99	10	9.39		2.4	1.02	(4, 15, 18, 27)	
Tungsten	19.2	3*	?	?	53	14.5	0.5	7.42				(14)	
Vanadium-51	4.7	3*	?	?	24	54	18	7.305	2.5	2.6	0.82	(5, 7, 27)	3.74-min V^{52}: 100(1.46)
Zinc	1.06	(2–3)*	?	?	48	29	17	9.51		2.8	0.60	(4)	250-d Zn^{65}: 25 (1.12)
Zirconium**	0.18	3*	?	?	113	35	4	8.66				(14)	65-d Zr^{95}: ~98 (0.750), 35-d Nb^{95}: 100 (0.764)

* For elements thus marked, number of unresolved photons has been determined; for all others only the intensity of resolved lines is given.

† Fraction, S, of available energy emitted by gamma rays with energy greater than E_m. E_m is the minimum gamma-ray energy observed in the measurement, it has no deep significance.

‡ "Complicated" means decay gammas above 750 kev are claimed to exist but the multiplicity of isotopes and/or the complexity of the decay schemes render estimations of intensities difficult. See reference (33) for data.

¶ Notation for decay gamma rays is as follows: half-life of decay-gamma emitter is given first, then number of decay gamma rays of each energy >750 kev per 100 neutron captures. Energy is in parentheses. Thus "9.58-min Mg^{27}: 10 (0.84), 2 (1.01)" means isotope emits 10 0.84-Mev and 2 1.01-Mev decay gamma rays per 100 captures.

§ Boron-10 decay gamma is from Li^7 following alpha decay of B^{11}.

** Capture-gamma-ray intensities for zirconium may be off by 50%.

†† For these elements, the highest-energy gamma ray is the only gamma ray present in the highest occupied energy interval. For lead, in addition, the seven 5–7-Mev gamma rays are all 6.73 Mev; for beryllium, in addition, the fifty 3–5-Mev gammas are all 3.37 Mev.

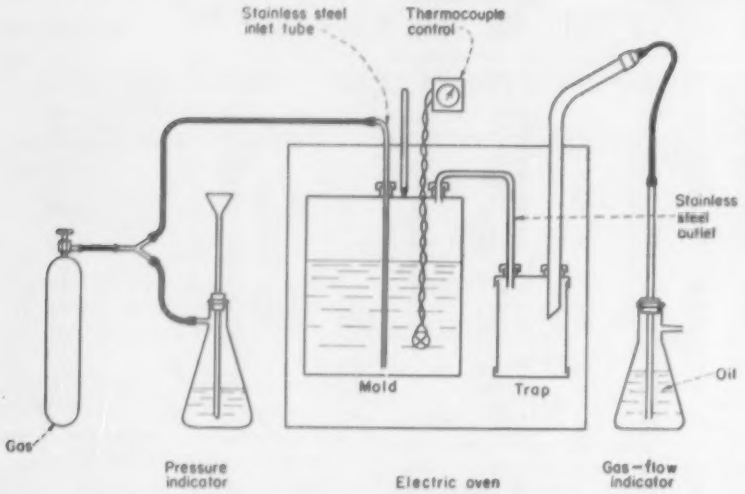

FIG. 1. In curing system, compressed-nitrogen bottle equipped with pressure reducer and needle valve is connected to oil-filled pressure indicator; funnel indicates pressure and serves as safety outlet. Stainless-steel inlet tube (some phosphors could be affected by hot copper or aluminum) is retractable through stainless-steel nipple having Teflon gland and pressure nut. Mold outlet (¼-in. stainless tubing) leads to trap (2-in. i.d., 8-in.-long pipe with endcaps). Trap outlet, ½-in.-diameter copper tube, extends inch into trap; and extending outside oven serves as condenser. Oil height above end of pipe in flow indicator determines gas pressure in mold. Laboratory-type electric oven has built-in manually controlled temperature regulator; slow clock motor can be coupled to regulator shaft for slow oven cooling. Thermocouple is fastened to outside of mold; thermometer indicates oven air temperature. Oil bath to dissipate heat of polymerization is not essential as surface-to-volume ratio is adequate for air cooling.

Preparing Large-Area Plastic Scintillators

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Large-area plastic scintillation counters of a relatively small thickness are useful for large-solid-angle counting and in experiments where high-energy particles or their scattered products may have to penetrate several counters in succession.

Counters containing large flat cells filled with liquid scintillators have been built in the past (*1*). However, plastic scintillators are often more convenient to use, since they can be easily machined to any required size and shape, and do not require a container; thus they are also preferable for particles near the end of their range that might otherwise be stopped by the container wall.

Preparations of plastic scintillators of small volumes have been described among others by Buck and Swank (*2*) who use a rather careful vacuum procedure. A somewhat simpler procedure for larger volumes has been briefly indicated by Wouters (*3*).

The simple laboratory method described here consistently produces clear plastic scintillators free from apparent strains and without size limitations. The necessary curing system may be reused many times.

Curing System

When small amounts of commercial styrene* or vinyltoluene,* containing an inhibitor, were heated in a small beaker covered with a watch glass and brought to a quick boil, clear samples could be produced with only a little surface yellowing. In this method, the monomer vapor would fill the beaker and partially escape. The yellowing was presumably caused by contact with the air that entered when boiling ceased because of advanced polymerization. The beaker would break as it cooled.

From the foregoing it was concluded that dissolved gases and any volatile impurities boiled out. Remixing of some of the condensing impurities was prevented in part by the thickening of the plastic. Vacuum bubbles did not appear because the beaker was always at atmospheric pressure.

Bubbling nitrogen through liquid scintillators considerably improved their pulse heights. This effect gradually disappeared after reexposure to air (*4*). An effect of this nature was thought useful also for plastic scintillators, especially when the chemical

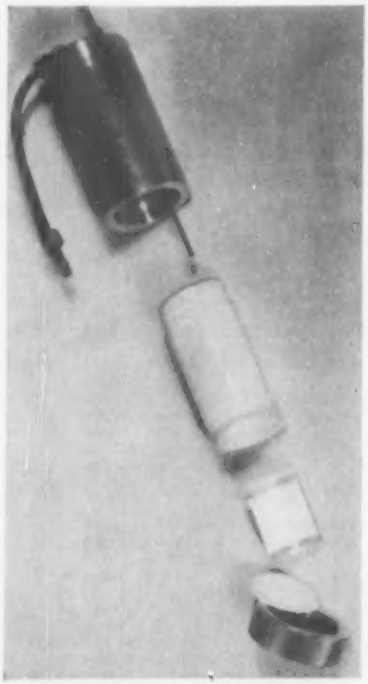

FIG. 2. For cylindrical molds, Teflon was used in construction since it permits reuse, and because of inertness, high-temperature softening point, and nonsticking qualities. Small mold, 1½-in. i.d., utilizes Teflon tubing and Teflon-sheet disk at its bottom. Ends of Teflon tubing are faced at an angle to permit flexible seal at inside edge. After plastic is cured, mold is taken apart and plastic pushed out

* Dow Chemical Company, Midland, Michigan.

additives would not permit boiling temperatures.

A system was then developed that applied the result of these experiences (see Fig. 1). Molds for cylindrical and flat scintillators are shown in Figs. 2 and 3.

Operation

The following remarks deal mainly with vinyltoluene plastics, although small polystyrene samples were also made using different temperatures.

The whole system is first flushed with nitrogen and tested for leaks. The gas inlet of the mold is then raised close to the top of the mold, and connected to a closed valve of a light vacuum system. The gas-outlet pipe of the mold is disconnected from the trap and dipped in a container holding the desired monomer and phosphor solution. Opening the vacuum valve sucks the solution into the mold; care should be taken not to suck air into the system. The mold should be less than ¾ full to permit safe boiling and expansion.

In preparing solutions, particularly those that would be supersaturated at room temperature (e.g., those containing 3–4% terphenyl), it is desirable to heat them and bubble nitrogen through them while they are being stirred. In such cases, the oven with the mold system is also preheated.

After the solution is in the mold, the pipes are reconnected, the inlet pipe lowered to the bottom of the mold, and nitrogen bubbled through at the rate of about two bubbles a second. The oven temperature is then permitted to rise. When the thermocouple reads about 120° C, the gas-inlet pipe is withdrawn to an inch or two above the top of the liquid in the mold. The meniscus in the pressure indicator stops falling when the gas-inlet pipe leaves the liquid while it is raised. When the thermocouple reading climbs to about 175° C, enough heat is developed in the mold due to polymerization to bring the contents quickly to the boiling point, around 180–185° C. Boiling is indicated by an increased bubbling rate in the flow indicator.

The oven controls should then be reduced and set to about 150–160° C. The exothermic reaction may maintain the boiling temperature for about ½ hr. Some of the vapors and impurities are polymerized in the trap, usually only a few percent of the mold contents.

When the mold temperature has stabilized, the gas flow may be reduced to about one bubble every 2 sec. After 6 or 7 days, the temperature may be reduced to about 80° C. Then it is reduced very slowly (about 2°/hr) to about 50° C to avoid straining the plastic as it hardens. Then it may be cooled more rapidly to room temperature to avoid recrystallization of the phosphor.

After the plastic has been removed, taking care not to damage the mold surface, the mold may be cleaned with a suitable solvent such as benzene or in a vapor degreaser with trichloroethylene to remove any residues.

The plastic can easily be machined, and may be finished, e.g., with Nos. 400 and 600 wet emery paper and polishing compounds like Putzpomade.*

Polyvinyltoluene softens and becomes pliable when heated to about 80° C or higher. This may conveniently be done in water. It may then be bent or pressure molded into new shapes and held until cool.

Discussion

The characteristics of plastic scintillators depend on the type of phosphor and the type and purity of the base plastic. Solutions of 2–4% terphenyl, and 0.02% tetraphenylbutadiene (Pilot Chemical Co.) or 0.07–0.1% diphenylstilbene (Pilot) as wavelength shifters,† were tried with vinyltoluene as a base. Diphenylstilbene (*6*) not only makes for a short decay time (less than 2.8×10^{-9} sec) (*6*), but, because it scintillates at shorter wave lengths, also appears to be more efficient when used with a photomultiplier tube with an S-4 response, e.g., RCA 6342.

The purity of the commercial vinyl-

* J. C. Paul and Co., Chicago.

† The smaller concentrations may reduce self-absorption in larger scintillators.

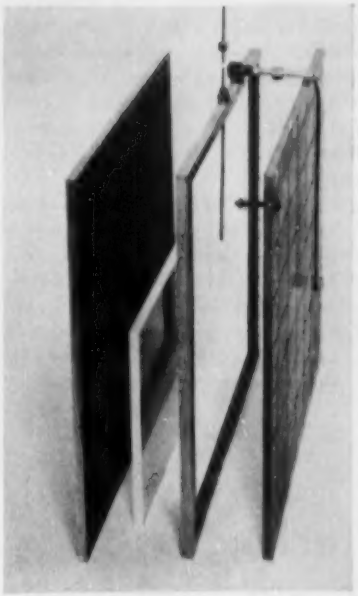

FIG. 3. For large flat molds, Teflon is not rigid enough; for mold shown here, aluminum is fuse-coated with thin Teflon layer [may be possible to use cementable Teflon sheets (United States Gasket Co., Camden, N. J.) or Teflon adhesive (Gilbreth Co., Philadelphia, Pa.)]. Mold is 16 × 12 in. and frame thickness ½ in. With thinner frames, gas outlet can be on one of plates. Aluminum parts are heated to 750° F; after cooling, they are scuffed with emery paper or steel wool and washed in alcohol. Insides of plates and inside and sides of frame facing plates are sprayed with thin coat (0.3 mil) of Teflon primer for aluminum (type 850-202; Teflon Finish, E. I. du Pont de Nemours). Parts are air dried and then baked at 750° F for 15 min (5). After cooling in water, surfaces are scuffed and smoothed with fine wet emery paper, washed with acetone and then with xylene. About 6 coats (1-mil thickness each) of Teflon Clear Finish (type 852-201) were applied; each coat was air dried and baked for 15 min at 750° F and quickly cooled in water; each coat except last was smoothed with fine wet emery paper; all were washed with acetone and xylene

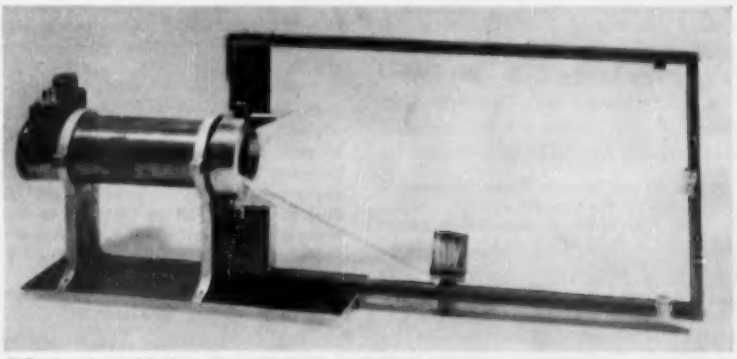

FIG. 4. Assembled counter prior to wrapping

toluene can of course be improved by distillation, but for counters where a small amount of self-absorption can be tolerated, it may be sufficient to bubble nitrogen through the fresh vinyltoluene and store it in a nitrogen atmosphere. Care should of course be taken to remove all the air from inside the mold parts.

In thin flat scintillators, most of the light is reflected many times before it reaches the photomultiplier tube. The number of reflections varies inversely with the thickness of the plastic. The light lost through reflections may be reduced by polishing all surfaces well.

Counters may be constructed by using polished Lucite (*1*) optically coupled to the scintillator, or hollow reflective light pipes to the photomultiplier tubes. The plastic may be wrapped in aluminum foil and made light tight with wide "Scotch" electrical tape. A counter is shown in Fig. 4.

In experiments involving time resolution in the millimicrosecond range, the travel time of direct and reflected light may become important. It takes about 1.5–1.6 mμsec for light to traverse a foot of the plastic in a straight line. Not only will a delay be introduced by the length of the plastic, but also the width of the resultant pulse will depend on the location of the scintillation. If the scintillator is wrapped in a reflecting material with the light being collected at one end, then the pulse will be widest when the scintillation originates near the light collecting point.

* * *

This work was supported by a joint program of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.

BIBLIOGRAPHY

1. R. L. Garwin, *Rev. Sci. Instr.* **23**, 755 (1952)
2. W. L. Buck, R. K. Swank, NUCLEONICS **11**, No. 11, 48 (1953)
3. L. Wouters, NUCLEONICS **12**, No. 3, 26 (1954)
4. J. R. Arnold, University of Chicago, private communication
5. "Teflon Finishes," du Pont new product technical bulletin, Bulletin No. 1, 4th ed.
6. R. K. Swank, NUCLEONICS **12**, No. 3, 14 (1954)

Techniques for Counting Radiokrypton

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Among the fission products now available from the growing number of nuclear reactors are several isotopes of krypton and xenon (*1*). Two of these isotopes, Kr^{85} and Xe^{133}, are radioactive, but the short half-life (5.3 days) of the latter greatly reduces its usefulness. Consequently, the following discussion will be limited to techniques for counting the 9.4-yr Kr^{85} with the understanding that the same techniques may be applicable to other radioactive gases that do not decay to a solid active daughter element.

Radiokrypton may, for practical purposes,† be regarded as decaying by emission of a 0.695-Mev beta particle to the stable isotope Rb^{85}. Beta particles of this energy may be counted by means of one of the several types of commercially available thin-window or thin-wall G-M tubes. The writer has found thin-wall tubes with a concentric glass jacket‡ to be quite satisfactory.

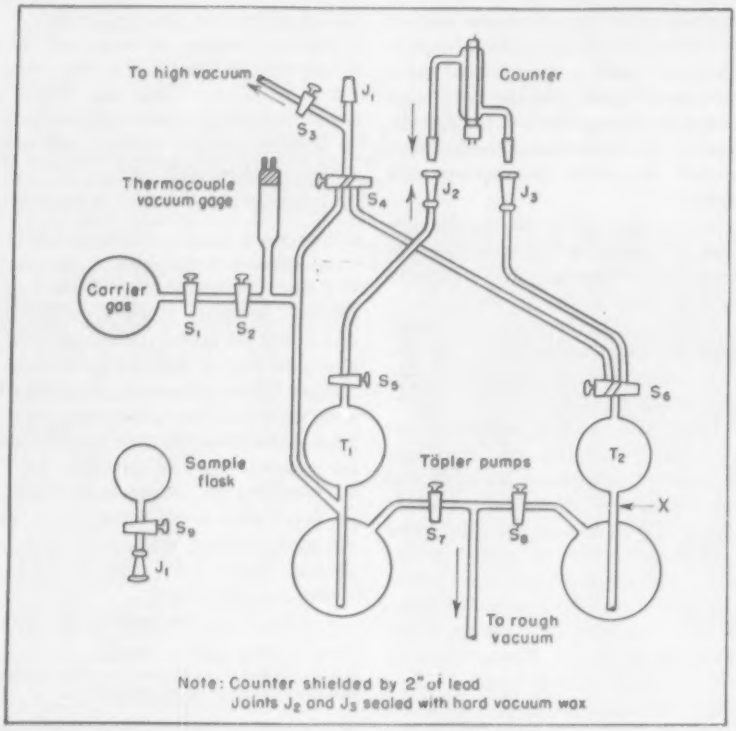

FIG. 1. Jacketed-counter system is suitable for determining relative specific activities of gases containing radiokrypton. Sample flask is attached at joint J_1 and complete system evacuated up to stopcocks S_2 and S_9. System is then closed off at S_2; after opening S_9, sample is transferred by Töpler pump T_1 into volume between S_5 and S_6, including counter jacket. If sample specific activity is too great, sample can be expanded through S_6 into upper bulb of Töpler pump T_2; with mercury level adjusted to calibration mark X, specific activity is reduced by $V_1/(V_1 + V_2)$ (V_1 = volume between S_5 and S_6; V_2 = volume between S_6 and calibration mark X). After expansion, S_6 may be reversed and mercury in T_2 raised, returning gas to sample flask through S_6. If inert krypton carrier is introduced into V_1 with pump T_1, expansion process can be carried out as many times as necessary to reduce specific activity to value permitting counter operation. V_1 and V_2 are measured by usual methods as system is assembled

The thin wall separating the annular jacket volume from the sensitive volume in these counters is stated by the

* The Knolls Atomic Power Laboratory is operated by the General Electric Co. for the U. S. Atomic Energy Commission under Contract No. W-31-109 Eng. 52.

† About 0.65% of this decay is by the coincident emission of a 0.15-Mev β-particle and a 0.54-Mev γ-ray. There is also a 4.5-hr isomer of Kr^{85} that will not be considered here because of its short half-life (*2*).

‡ Available from Nucleonic Company of America, Brooklyn 31, N. Y., and Radiation Counter Laboratories, Skokie, Ill.

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manufacturers to have a thickness of about 30 mg/cm², although this necessarily varies considerably from counter to counter. The counters used in this laboratory during the past several years have had jacket volumes of 3–10 cm³ and combined geometry and absorption factors for radiokrypton ranging from perhaps 0.05 to 0.20; that is, from 5 to 20% of the disintegrations occurring in the jacket are effective in producing counts. If the pressure in the counter jacket is limited to one atmosphere, and 1 cps above background is set as a practical lower limit on counting sensitivity, the lower limit on specific activity of the krypton-containing gas sample is between 0.5 and 7 dps/cm³, depending upon the physical configuration of the particular counter used. Since one curie of radiokrypton occupies approximately 0.6 cm³ under standard conditions, this corresponds to less than 10^{-10} cm³ of radiokrypton per cm³ of sample. Handling samples of this dilution is of course feasible only when sufficient stable krypton is present as carrier to prevent adsorption loss on the counting-system walls.

A system using a jacketed counter is shown in Fig. 1. If carrier gas is introduced when needed and is thoroughly mixed with the sample gas, this system will accommodate samples ranging in specific activity from a few disintegrations per second per cm³ to several millicuries per cm³.

The jacketed-counter system is suitable for determining the relative specific activities of gas samples containing radiokrypton, since the geometry and absorption factor for jacketed counters cannot be computed.

For absolute counting, it is feasible to introduce the radioactive gas sample directly into the sensitive volume of a counter of known physical dimensions. Such a counter has been described by Mann and Parkinson (3). This counter (Fig. 2) consists of two units identical except for cathode length. The difference in the counting rates in the two units may be taken as the disintegration rate of the gas in a volume equal to the difference in their sensitive volumes, which is assumed to be equal to the difference in cathode volume.

After introducing the sample into the counter along with counting gas and quenching vapor, the plateau may be determined for each unit of the counter. The difference in counting rates in the two units is easily determined graphically if the starting points

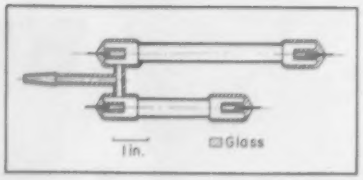

FIG. 2. Counter for absolute measurements

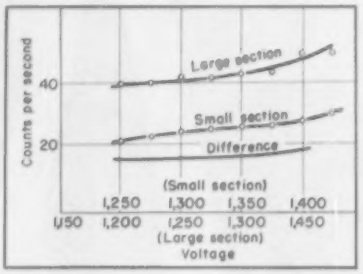

FIG. 3. Axis translation permits determining counting-rate difference between two units of absolute counter

of the two plateaus are brought into coincidence by translation along the voltage axis (Fig. 3).

If the sample is not excessively diluted with air, the pressure and composition of the counting gas is not critical. A mixture of about 85 mole % argon and 15 mole % of organic quenching vapor, to give a total pressure of 20–25 cm mercury, including the radioactive sample, has been satisfactory. The organic quenching vapor may be ethane, cyclopropane, ethyl acetate, or any one of several other compounds.

A system using the Mann and Parkinson type counter is shown in Fig. 4. This system, in contrast to the previous one, gives an absolute value for the total activity of a gas sample. However, if the specific activity of the sample is greater than a few hundred dps/cm³, use of the absolute counting system becomes difficult and the ultimate accuracy obtained is open to question. It is suggested that if many radiokrypton samples of wide variation in specific activity are to be counted, both systems should be available. Samples of low specific activity that have been counted with the jacketed-counter system can also be counted with the absolute system, thereby calibrating the much more flexible jacketed-counter system.

For those not familiar with G-M counter techniques and gas manipulations, a number of excellent texts are available (4–7).

BIBLIOGRAPHY

1. H. G. Thode, R. L. Graham, *Can. J. Research* **25A**, 1 (1947)
2. J. M. Hollander, I. Perlman, G. T. Seaborg, *Rev. Mod. Phys.* **25**, 469 (1953)
3. W. B. Mann, G. B. Parkinson, *Rev. Sci. Instr.* **20**, 41 (1949)
4. S. A. Korff, "Electron and Nuclear Counters" (D. Van Nostrand Co., Inc., New York, 1946)
5. M. D. Kamen, "Radioactive Tracers in Biology" (Academic Press, New York, 1947)
6. A. Farkas, H. W. Melville, "Experimental Methods in Gas Reactions" (Macmillan Co., New York, 1939)
7. A. Klemenc, "Die Behandlung und Reindarstellung von Gasen" (Akademische Verlagsgesellschaft, Leipzig, 1938)

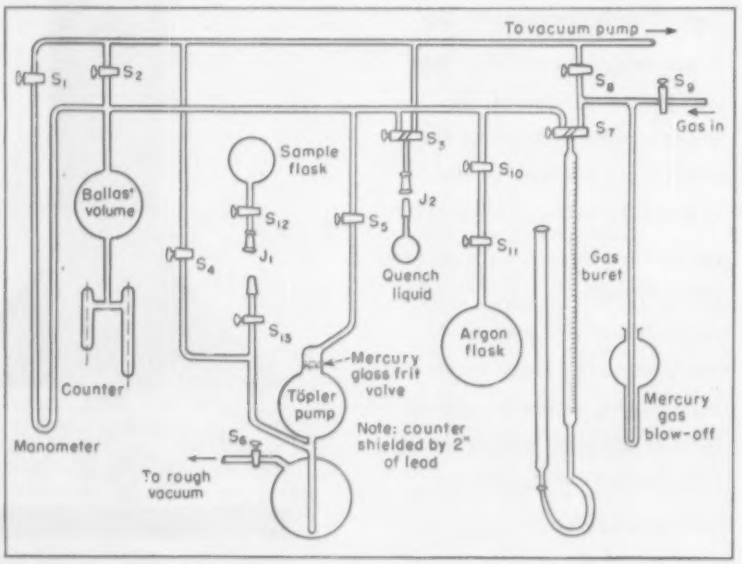

FIG. 4. In system using absolute counter, sample flask is attached at J_1; sample is introduced by Töpler pump. Quenching vapor from liquid in small flask is introduced through S_3 followed by argon from flask. Gas buret can be used to add other gases, as well as to provide measured volumes of gas for determining volume of system

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Counting Techniques for Chlorine-36

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Since chlorine-36 decays with a 4.4×10^5-year half-life (*1*) [beta particle of 0.714 Mev maximum energy (*2*); no associated gamma rays have been found (*1*)], it was thought that Cl^{36} could be conveniently detected by counting a slightly soluble chloride with a thin-window G-M or proportional counter, or by immersing a thin-wall glass tubular G-M counter in a solution containing Cl^{36}. The results of this investigation indicate that both mercurous and silver chlorides are suitable precipitates for counting Cl^{36}.

Experimental

Chemically pure or analytical-reagent-grade chemicals were used without further purification. Five and one-half milliliters of 0.37*F* hydrochloric acid containing 20 μc of Cl^{36} were obtained from Oak Ridge. Standard active solutions of potassium chloride were prepared by inoculating weighed amounts of potassium chloride with the active hydrochloric acid solution and diluting to volume.

Mercurous Chloride Precipitate

Twenty milliliters of an active potassium chloride solution were treated with a few drops of a dilute alcoholic solution of aerosol and then with a 20% excess of 0.03*F* mercurous nitrate solution that was 0.1*F* in nitric acid. After standing at room temperature for about 2 min, the precipitate was filtered with suction on tared, 26-mm-diameter Whatman No. 50 paper with the paper clamped between a ground-edge glass chimney, 3½ in. high and 18 mm. i.d., and a Hirsch funnel without sides and with its surface ground flat. After all but a few milliliters of the supernatant liquid had passed through the filter, the precipitate was intermittently stirred and washed with a stream of alcohol (approximately 15 ml), taking care to maintain the liquid level in the chimney above that of the precipitate until after the final washing.

Counting procedure. The mercurous chloride was dried at 60° C for 10 min, weighed, and then mounted for counting on a $2\frac{1}{2} \times 3\frac{1}{2} \times \frac{1}{16}$-in. dural plate with Scotch tape directly over the sample. The samples were placed in a holder about 2.5 mm below the 1.1-mg/cm² Mylar window of a methane-flow proportional counter operated at atmospheric pressure and 4,000 volts. A model PA-1 pulse amplifier fed into a model SC-2 scaler supplied by the Los Alamos Scientific Laboratory.

Reproducibility of results. To determine whether the chloride was quantitatively precipitated and would yield reproducible counting rates, ten samples were prepared from ten equal aliquots of a stock solution of active KCl. The calculated KCl concentration in each aliquot was equivalent to 59.02 mg of Hg_2Cl_2.

Excellent agreement was obtained among the counting rates, the deviations being within the statistical fluctuations of the counting rates (*ca.* ± 1%). Also, the weights of the precipitates were within 0.3% of the calculated value.

Effect of experimental conditions. Preliminary experiments indicated that slow oxidation of the acid $Hg_2(NO_3)_2$ solution gave rise to incomplete precipitation of the chloride. This was overcome by adding free mercury to the reagent.

Drying for as long as 24 hr at 60° C had no noticeable effect on the weight of the precipitate.

In precipitating Hg_2Cl_2 from solutions of varying nitric acid concentrations, both the precipitate particle size (as evidenced by the rate of settling) and the yield decreased with increasing acid concentration. In the range 0.01–1.0*F* nitric acid, the yield decreased from 99.9% to 99.3%, respectively; in 6.0*F* nitric acid, the yield dropped to 94.1%. Samples prepared from 0.1–6.0*F* nitric acid solutions were more uniform in appearance than those prepared from 0.01*F* solutions.

Varying the excess of $Hg_2(NO_3)_2$ from 20% to 400% did not affect the yield of mercurous chloride precipitated from 0.01*F* nitric acid.

The variation of the counting rate with sample weight was investigated as follows. A given amount of activity was added to various quantities of chloride, which yielded precipitate thicknesses of 11.8–31.5 mg/cm². These were mounted and counted as described previously. The results of 20 such experiments indicate that the counting rate decreased linearly at the rate of 0.91% per mg/cm² increase in sample thickness. Samples prepared from less than 30 mg of precipitate, corresponding to 11.8 mg/cm², were not uniform in appearance and did not yield reproducible counting rates.

Silver Chloride Precipitate

Ten milliliters of an active KCl solution in a 50-ml centrifuge cone were acidified with nitric acid and treated with a 20% excess of 0.06*F* $AgNO_3$ solution; the final reaction mixture was 1*F* in nitric acid. The precipitate was stirred approximately 4 min to insure coagulation, the walls of the cone were washed with alcohol to prevent creeping of the precipitate, and the whole centrifuged. The resulting curdy precipitate was transformed into a more crystalline one by washing with three 20-ml portions of absolute alcohol with 1-min agitation during each wash. The AgCl was washed into a chimney with alcohol, filtered, dried at 60° C for 10 min, weighed, and then mounted as described for Hg_2Cl_2.

Reproducibility. The quantitativeness of the precipitation and reproducibility of the counting rates were checked with six 71.7-mg samples as outlined for Hg_2Cl_2. The counting rate deviations were within the statistical fluctuations of the counting rates (ca. ± 1%) and the weights of the precipitates were within 0.4% of the calculated values.

Effect of conditions. Drying for 15 hr at 60° C had no noticeable effect on the weight of the precipitate.

Precipitates formed in nitric acid concentrations less than 0.05*F* were colloidal and did not coagulate.

The darkening of the precipitate on exposure to light had no perceptible effect on the counting rate. For example, the counting rates of six samples exposed to normal laboratory lighting conditions for a month remained constant within the statistical fluctuations of the counting rates.

The variation of counting rate with sample weight was determined as out-

lined for mercurous chloride. Twenty-four experiments indicated that the counting rates for samples ranging from 8.0 to 40.0 mg/cm² decreased linearly at the rate of 0.78% per mg/cm² increase in sample thickness. Samples less than 8.0 mg/cm² were not uniform in appearance and did not yield reproducible counting rates.

Dip Counters

Three dip counters (Nuclear Instrument and Chemical Corp., model D52; Radiation Counter Laboratories, mark 1 model 81; and Tracerlab, model TGC-5) were studied in duplicate. The pulses were fed directly into the discriminator of a NICC model 161 Scaler (scale of 64).

Each dip counter was tested for reproducibility of counting rates as follows. An aliquot of a stock solution of activity was diluted to a given volume in a tube that was then slipped over the dip counter in a reproducible manner. After the activity was counted, the counter and sample tube were rinsed with distilled water and dried. This procedure was repeated three times with each dip counter; a background was determined before each liquid sample was counted. In each instance, the deviations of the four counting rates were within the statistical fluctuation of the counting rates (*ca.* ± 1%). Apparently no detectable activity remained on the counters after rinsing with water, as evidenced by the constancy of the background between rinses.

The variation of counting rate with density of the liquid sample was studied by counting active aqueous solutions of NaCl, $BaCl_2$, and methanol. For each counter, the linear decrease in counting rate was 0.6% per 0.01 gm/cm³ increase in density in NaCl and $BaCl_2$ solutions ranging from 1.000 to 1.190 gm/cm³; in methanol solutions of 0.820–0.995 gm/cm³, the linear decrease in counting rate was 1.0% per 0.01 gm/cm³ increase in density.

Counting Efficiencies

To determine the relative efficiencies of the counting techniques, liquid samples and 40-mg equal-activity samples of Hg_2Cl_2 and AgCl were counted.

The counting rates of the two precipitates were essentially the same. The Tracerlab and Radiation Counter Laboratories counters, which used 18-ml and 12-ml samples, respectively, yielded counting rates $\frac{1}{20}$ as great as those of the precipitates; the Nuclear

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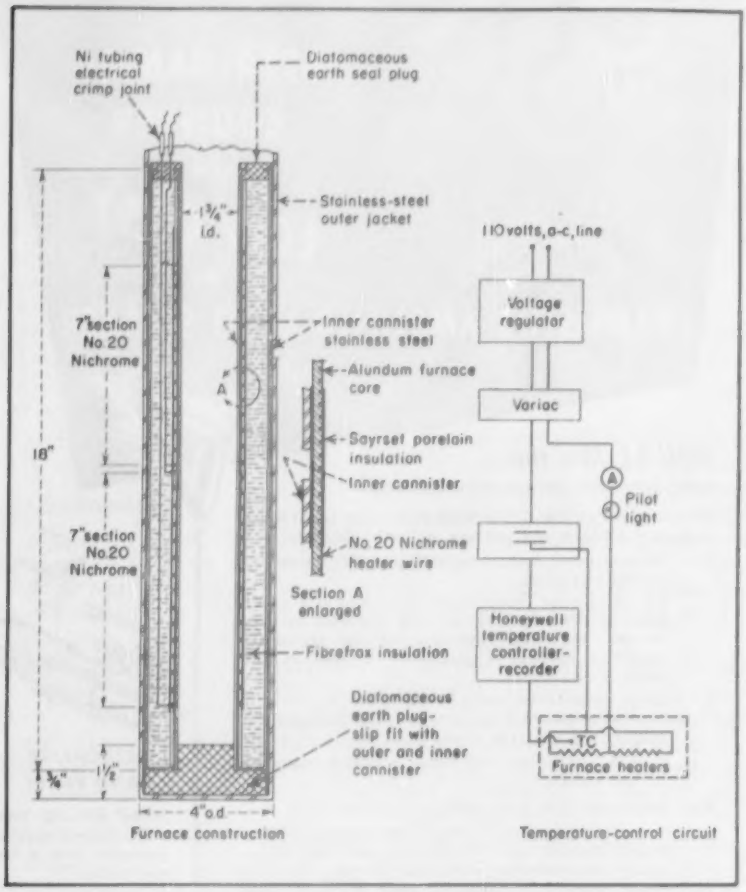
Instrument and Chemical counter, which used 12-ml samples, yielded counting rates $\frac{1}{15}$ as great as those of the precipitates. In all instances the liquid layer surrounding the counter was approximately 2.5 mm thick. Because the liquid tends to creep up irregularly in the annular space between the counter and sample tube when the liquid layer approaches a thickness of 1 mm, it is doubtful that the efficiency of the dip counters could be much more than doubled by using smaller sample volumes.

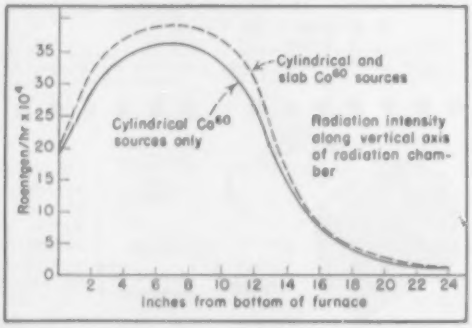
This article is based on work done under the auspices of the U. S. Atomic Energy Commission and the Los Almos Scientific Laboratory.

BIBLIOGRAPHY

1. C. Wu, C. Townes, L. Feldman, *Phys. Rev.* **76**, 692 (1949)
2. L. Feldman, C. Wu, *Phys. Rev.* **87**, 1091 (1952)



CANISTER-TYPE FURNACE permits easy installation and removal from irradiation tube. Thermocouple embedded in glass sample-support rod measures temperature and activates Brown recorder-controller; there is no noticeable radiation effect on thermocouple



TWO COBALT-60 SOURCE ARRAYS are used: cylindrical (1,800 curies, 13¾ in. long, 2.3 in. o.d.) sources only and combined cylindrical and flat (300 curies, 2¼ × ⅜ × 14 in.) sources (latter shown in Cerenkov-glow photograph). Aluminum-clad sources surround bottom of irradiation tube containing experimental setup and furnace. Radiation fields along vertical axis of irradiation tube (see graph) were determined by chemical-dosimetry and ionization-chamber techniques; sharp fall-off simulates field at surface of radioactive waste tank

High-Temperature Underwater Irradiation Facility

By FRED HITTMAN and OTTO A. KUHL
Fission Products Utilization Project
Brookhaven National Laboratory
Upton, New York

In our investigations into the concentration, storage, and utilization of radioactive wastes, a facility was required for determining the effects of high-intensity gamma irradiation on various structural materials and chemical systems at temperatures ranging from room temperature to 500° C.

To make this facility economical and versatile enough for other types of irradiation studies, we decided upon an underwater irradiation chamber in which each component is an easily removable separate unit and in which a variety of dose rates can be realized.

A 13-ft-long, 4-in.-diameter thin-walled stainless-steel tube welded shut at one end serves as the primary irradiation chamber. This tube and the Co^{60} sources are held in position at the bottom of the 10-ft-deep BNL water canal by means of a stainless-steel jig. A simple clamping device fastens the chamber to the top of the canal bulwark. High temperatures are provided by a canister-type electrical furnace that fits the irradiation chamber.

Four high-temperature irradiation tubes have been constructed and are in daily use. Two are utilized in a radiation field, and the other two operate concurrently as controls. Initial studies on the effects of gamma radiation on high-temperature corrosion and on the stability of fused salt systems are in progress.

* * *

This research work was carried out under the auspices of the U. S. Atomic Energy Commission.

MISSILE SYSTEMS

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Missile Systems Division scientists and engineers discuss a new missile systems concept in light of tactical requirements. Left to right: Dr. H. H. Hall, nuclear physicist; I. H. Culver, systems development division engineer; Dr. R. J. Havens, research scientist; W. M. Hawkins, chief engineer; Dr. Ernst H. Krause, nuclear physicist and director of research laboratories; S. W. Burriss, experimental operations division engineer; Ralph H. Miner, staff engineering division engineer; and Dr. Eric Durand, nuclear physicist.

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Argon Treatment of Liquid Scintillators to Eliminate Oxygen Quenching

By DONALD G. OTT, F. NEWTON HAYES, JAY E. HAMMEL, and JOHN F. KEPHART
Los Alamos Scientific Laboratory of the University of California
Los Alamos, New Mexico

The presence of very small amounts of foreign material in a scintillation medium may have a profound effect on scintillation efficiency. A considerable quenching effect can be attributed to dissolved oxygen in liquid-solution scintillators (*1*). The mechanism of this quenching is not clear; it may involve the formation of photodimers or photooxides, or interference with early stages of energy-transfer processes.

Displacement of the oxygen by bubbling nitrogen into the scintillator solution has been reported by Arnold (*2*) to increase the relative pulse height by 20–30%. Although a somewhat inconsistent degree of oxygen quenching was observed by Pringle *et al.* (*1*), it appears that the "sea-level air-quenching factor" is approximately 0.75; i.e., an improvement of about 33% was noted when oxygen was removed from various solutions by nitrogen bubbling.

The solubility of oxygen in toluene at 18° is 240 mg/l of toluene (*3*). At Los Alamos, the partial pressure of oxygen in air is approximately 580 × 0.2 or 116 mm; therefore, oxygen is present in toluene to the extent of about 0.037 gm/l. This amount is quite large considering that wavelength shifters are effective in concentrations of 0.01 gm/l (*4*).

In the present investigation, the use of argon rather than nitrogen was suggested principally by two factors:

1. Reproducible results with nitrogen can be obtained only by use of a cumbersome purification train of alkaline pyrogallol and magnesium perchlorate (*1*).

2. Argon, which has a greater density with respect to air (1.38), should provide a better protective blanket over the scintillator solution in detectors that are not completely sealed.

The exchange of gases in solution is surprisingly rapid. No improvement in pulse height was noted when a sample was pipetted from a nitrogen-flushed solution and then measured—apparently equilibrium was established with the air during the brief transfer period.

Small-Sample Effect

Experiments in which the dissolved air was displaced with argon were first done utilizing 25-ml samples and the previously described (*4*) relative-pulse-height system. Ten minutes of bubbling by means of a sintered-glass gas disperser was sufficient; no further increase in pulse height was observed after longer periods.

The table gives the results obtained with representative systems. The solutes *p*-terphenyl and 2,5-diphenyloxazole in toluene or xylene gave essentially the same quenching factors. The slightly greater pulse height for toluene as compared to xylene may be attributed to the longer light path; with smaller samples (1 ml), xylene is a somewhat better solvent than toluene (*4*). The last column, the Los Alamos air-quenching factor, leads to the expectation of an approximately 23% pulse-height increase in detectors at Los Alamos if quenching occurs during energy-transfer processes and not after emission of light, from which point detector dimension and reflector effects begin to be important.

Air-Quenching Factors Found at Los Alamos

Solvent	*Solute*	*Conc. (gm/l)*	*R.P.H.*	*Quenching factor*
Toluene	*p*-terphenyl	3	0.75	0.82
Toluene	PPO	3	1.00	0.81
Xylene	*p*-terphenyl	3	0.70	0.80
Xylene	PPO	3	0.98	0.83

Large-Volume Detector

The success with small sample volumes prompted application of the method to a large detector. A Los Alamos detector, containing about 60 l of 4-gm/l terphenyl plus 0.5-gm/l POPOP in toluene, was flushed with argon for 15 min by means of a sintered-glass gas disperser, which extended to the bottom through the center opening in the top of the tank. Argon pressure was also applied to the outlet on the small reservoir while the disperser was removed and the cap replaced on the center opening. This pressure (~0.5 lb) was maintained on the reservoir outlet to prevent the possibility of air diffusing into the tank.

The results with the large detector were essentially the same as for small samples; i.e., a 21% pulse-height increase was obtained.

The tank filling was modified to contain 10% methanol and 3.4% cadmium propionate. Argon bubbling again improved the pulse height by 21%.

At the present time, the plastic scintillator producing the highest pulse height,* as measured with an aluminum reflector, is one of polyvinyltoluene containing 36 gm/l terphenyl and 0.9 gm/l *p,p'*-diphenylstilbene. A *p*-xylene solution of 10-gm/l PBD [2-phenyl-5-(4-biphenylyl)-1,3,4-oxadiazole], after oxygen removal by bubbling with argon, gives a pulse height of 1.36 relative to this best plastic. This value is 0.70 relative to the best anthracene crystal available. For comparison, 5 gm/l terphenyl in toluene after oxygen removal has a pulse height relative to anthracene of 0.48, and a toluene solution of 5-gm/l terphenyl plus 0.5-gm/l POPOP gives 0.62.

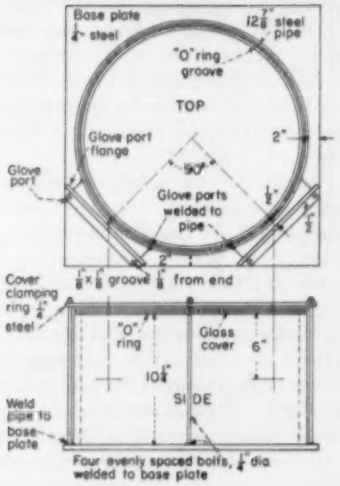
* * *

This work was performed under the auspices of the U. S. Atomic Energy Commission.

BIBLIOGRAPHY

1. R. W. Pringle *et al.*, *Phys. Rev.* **93**, 1582 (1953)
2. J. R. Arnold, *Science* **119**, 155 (1954)
3. International Critical Tables, vol. 3, p. 264 (McGraw-Hill Book Co., Inc., New York, 1928)
4. F. N. Hayes *et al.*, LA-1639 (1953)

* Prepared by W. L. Buck, Argonne National Laboratory.



Small Dry Box for Phosphors

By WAYNE A. CASSATT, Jr.,* and W. WAYNE MEINKE
Department of Chemistry
University of Michigan
Ann Arbor, Michigan

Handling hygroscopic materials such as the sodium iodide crystals used in scintillation counting requires a dry atmosphere. The dry box described here, providing sufficient room for polishing and mounting crystals, attains a dry atmosphere by overnight exposure to a dessicant.

The box (Fig. 1) was constructed by welding a 10-in.-long, 13-in.-dia. iron pipe to a base plate of ¼-in. sheet steel 17 in. × 17 in. square. Two short sections of 6-in. pipe were welded onto the side of the large vertical pipe to act as glove ports. A clamp ring, fastened by long bolts to the base plate, holds a glass cover and neoprene gasket on the top of the box. The top edge of the

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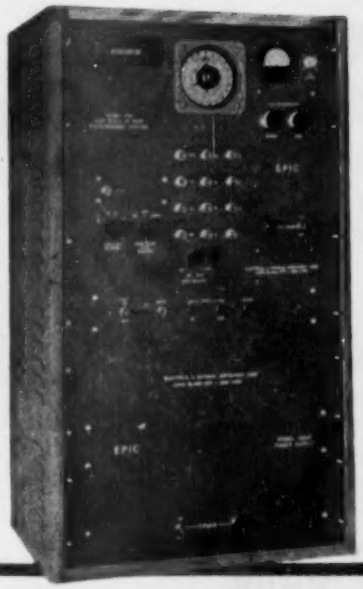

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vertical pipe is machined smooth and the neoprene gasket lubricated with Dow-Corning stopcock grease to form a moisture-proof seal. Flanges were welded to the pipes forming the glove ports so that standard-type dry-box, glove clamping rings* could be bolted on. The inside of the box was painted with several coats of white Amercoat No. 33 and the outside with gray Amercoat. The entire assembly can be fabricated for about $85.

* * *

This work was supported in part by the U. S. Atomic Energy Commission.

* Available from Radioisotopes Applications Co., 1834 University Avenue, Berkeley, Calif.

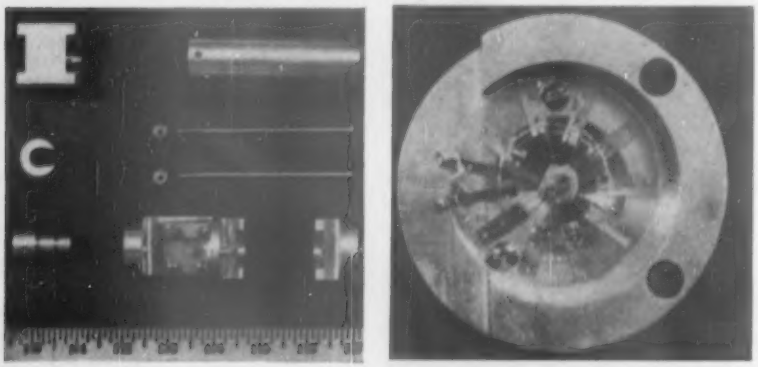

FIG. 1. Left: diassembled neutron-sensitive U^{235} thermopile unit; right: thermocouple array with U^{235} deposit at center

U^{235} Neutron Thermopile Provides Greater Sensitivity

By T. RICHARD HEROLD
Works Technical Department
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E. I. du Pont de Nemours & Co., Inc.
Augusta, Georgia

In recent years, new applications of the neutron thermopile (neutron "thermometer") demanding greatly improved sensitivity prompted development of the U^{235} thermopile. While possessing greater sensitivity than the B^{10} models (*1, 2, 3*), the U^{235} thermopile retains the characteristics of low impedance, compactness, and simple construction (see table) (*4*).

Investigations conducted at Oak Ridge National Laboratory indicated that U^{235} was the optimum "hot"-junction material. The Brown Instrument Radiamatic thermopile was the best available thermocouple assembly for the application.

The problem of attaching the neutron-sensitive coating to the thermocouple junctions (*5*) is multiplied in the case of U^{235}. In addition to the external neutron bombardment, any adhesive must withstand internal bombardment by fission fragments and maintain a constant minimum thermal resistance. Electroplating techniques, sputtering, and evaporation processes proved inadequate for the U^{235} model. It was decided to employ a suspension of U^{235} particles (30–40 micron size) in a neutron-flux-resistant material that could also withstand the internal bombardment of fission fragments. Sauereisen No. 1 cement was used.

A suitable housing for the thermopile unit also involves considerations of size, sensitivity (in both isotropic and anisotropic fluxes), compensation for ambient temperature variations, stacking of units for additional output, signal-cable connections, and irradiation effects on construction materials (*6*). These criteria evolved the design shown in Fig. 1. Such an arrangement facilitates mounting several thermopiles, complete with their temperature-compensating thermopiles, in a case only a few inches in length. Construction materials are 2S aluminum and Dow magnesium-aluminum alloy.

Characteristics of U^{235} and B^{10} Thermopiles

Manufacturer	*Output at 10^{11} nv (millivolts)*	*Usable range (nv)**	*Time constant (sec)*	*Ambient temp. effects*
Boron thermopiles				
University of Chicago Met. Lab.	1.0	10^9 to 10^{12}	4	Neg. effect for temp. change of 2.5° C/min (*7*)
Nuclear Inst. & Chem. Corp.	0.5	2×10^8–10^{12}	4	Same as above
Brown Inst. Div.	0.85	10^9–10^{12}	4	No data
U^{235} thermopile				
Experimental unit	19.30	5×10^7–10^{12}	20.4	No data

* Upper limit of range selected on basis of burnup rate of neutron-sensitive coatings, insulator stability, and linearity; lower limit selected on basis of minimum signal required for millivolt recorders or potentiometers—approximately 10 μv. Limits could be extended by improved design and geometry (*10*) and by special, high-gain d-c amplifiers.

Operational Fundamentals

A complete theory of operation of the neutron thermopile was evolved, based upon probability, neturon mechanics, and reactor kinetics (*7, 8*).

The problem was resolved to one of thermal equilibrium states, or "heat balances" (*9*). In brief, the initial calculation determines a steady-state quantity of heat produced per unit of time by neutron interactions in the "hot"-junction material. A steady-state quantity of heat is then considered to flow from the "hot"-junction material to the "cold" thermocouple junctions. This heat flow then establishes a temperature gradient that gives rise to the thermoelectric output. Conduction and radiation losses along the thermocouple wires and radiation losses from the "hot"-junction material were considered, utilizing the Fourier concepts of heat conduction and the Stefan-Boltzmann law of radiating bodies. The inherent thermal time lag in the instruments' response to step changes in neutron flux was also considered by employing the analogous

electrical counterpart of the thermopile shown in Fig. 2.

Testing

The U^{235} unit was tested in one of the downbeam holes of the Low Intensity Testing Reactor. The neutron flux was determined at several positions by exposing samples of pure cobalt wire. The output received from the U^{235} thermopile at these same positions as a

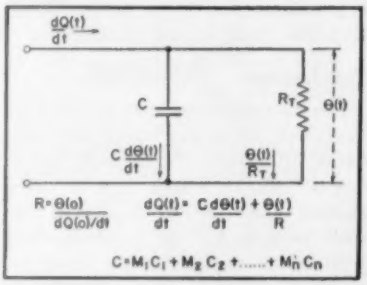


FIG. 2. Electrical analogy of thermopile

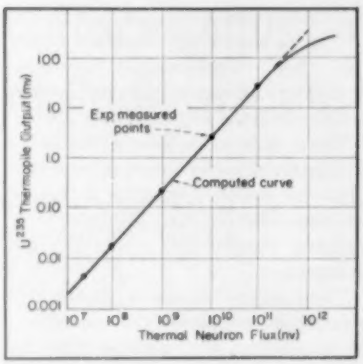


FIG. 3. Computed and measured values of U^{235} thermopile output vs neutron flux

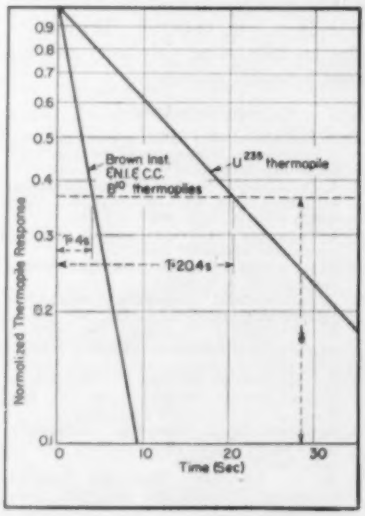
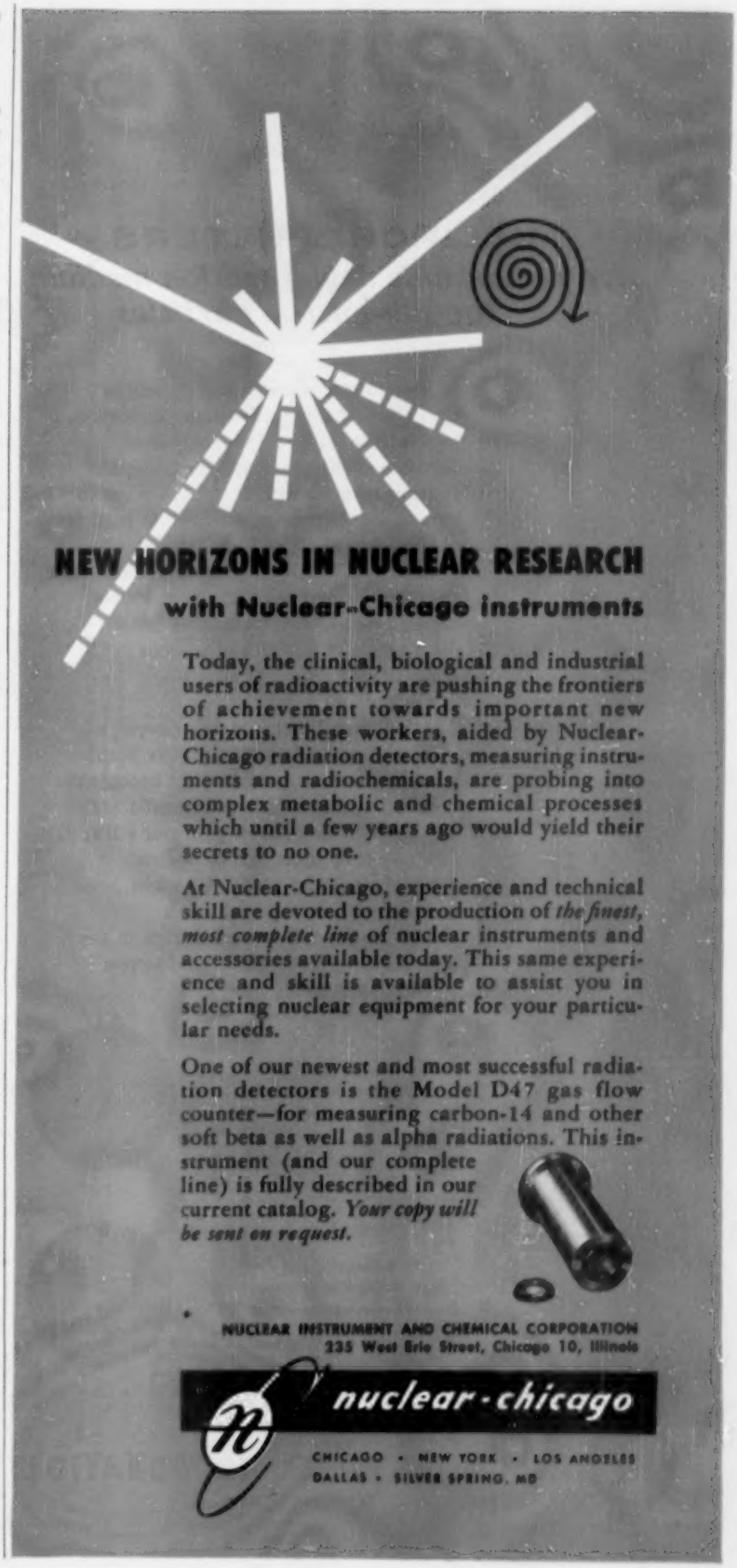


FIG. 4. Decay curves of thermopiles when subjected to step change in neutron flux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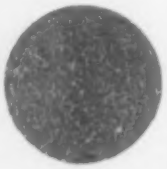
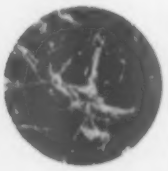


Photomicrograph of dense high quality filter paper surface. Magnification approximately 100 x



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function of neutron flux is shown in Fig. 3.

The curves of Fig. 4 are normalized plots of actual decays of the various thermopiles' output when subjected to a step reduction in neutron flux. The outputs were recorded by a 3-mv continuous balance potentiometer with a 1-sec pen drive (for full-scale deflection) and a chart speed of 1 in./sec. The fall time (90–10%) of the step change in neutron flux was about 0.2 sec, as measured by a boron-coated ionization chamber and oscillograph.

Conclusions

The increased sensitivity of the U^{235} thermopile facilitates linear measurements of neutron fluxes from below 5×10^7 nv to above 5×10^{11} nv. Stacked units can easily reduce the lower limit to 5×10^6 nv, suggesting applications in the period range of nuclear reactors.

The comparatively poor response time can be substantially reduced by improving the deposition technique, whereby U^{235} is geometrically dispersed about the "hot" thermocouple junctions. A better adhesive material would further decrease response time (*10*).

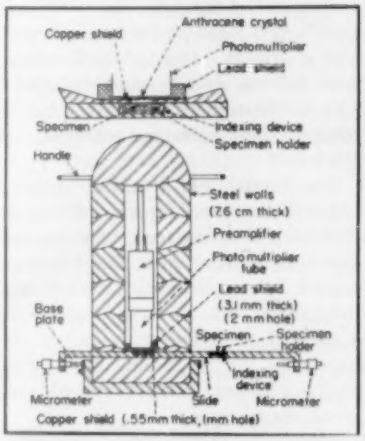
The long-term stability of the adhesive material under internal bombardment by fission fragments is yet to be determined. The full effects of ambient temperature variations are unknown.

The increased sensitivity of the U^{235} thermopile enhances the possibility of minimizing the response time by employing *RC* compensating networks or thermal feedback as a means of electronic compensation.

With a radioactive source within the "hot"-junction material, thermopiles offer an interesting possibility as constant potential sources.

BIBLIOGRAPHY

1. G. Barbaras, *et al.* Design and construction of boron coated thermopiles for use in neutron fields—introduction, AECD-2485 (1949)
2. A. C. Lapsley. Neutron flux measurements with thermopiles, NUCLEONICS **11**, No. 5, 62 (1953)
3. A. C. Lapsley. A compact neutron sensitive thermopile, ANL-4839 (1952)
4. J. M. Harrer. Reactor operations, NUCLEONICS **11**, No. 6, 35 (1953)
5. G. Barbaras, *et al.* Deposition of pure boron, MDDC-1339 (1947)
6. R. K. Abele, J. Gundlach. The neutron sensitive PCP ionization chamber, ORNL 1080 (1951)
7. S. Glasstone, M. C. Edlund, "Elements of Nuclear Reactor Theory," p. 92 (D. Van Nostrand Co., Inc., New York, 1952)
8. H. Soodak, E. C. Campbell, "Elementary Pile Theory," pp. 1, 18 (John Wiley & Sons, Inc., New York, 1950)
9. M. W. Zemansky, "Heat and Thermodynamics" (McGraw-Hill Book Co., Inc., New York, 1951)
10. Electronic Nuclear Instrumentation Group, M. I. T. Annual Progress Report (March 1, 1953)



SCINTILLATION-DETECTOR UNIT for following surface diffusion on metal surface

Following Surface Diffusion of Radioisotopes

By N. H. SIMPSON* and NORMAN HACKERMAN
Department of Chemistry
University of Texas
Austin, Texas

During an investigation of surface self-diffusion on copper,† it was necessary to develop a method for determining the concentration of the radioactive Cu^{64} atom at various sites on the surface of a single copper crystal. The method finally used was an adaptation of a scintillation counter, which used an anthracene crystal and a DuMont 6292 photomultiplier tube (see illustration).

The anthracene crystal was small (2 mm thick and 2 mm in diameter) to discriminate against gammas. However, the thickness of the crystal exceeded the maximum range of the beta particles in anthracene.‡

The anthracene crystal was mounted

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* Present Address: Chief of Engineering Test Laboratory, Convair, Fort Worth, Texas.

† A paper on "Rate of Surface Diffusion Over The Principal Planes of A Single Crystal of Copper," to be published later.

‡ R. T. Carr, G. J. Hine, Nucleonics **11**, No. 11, 53 (1953).

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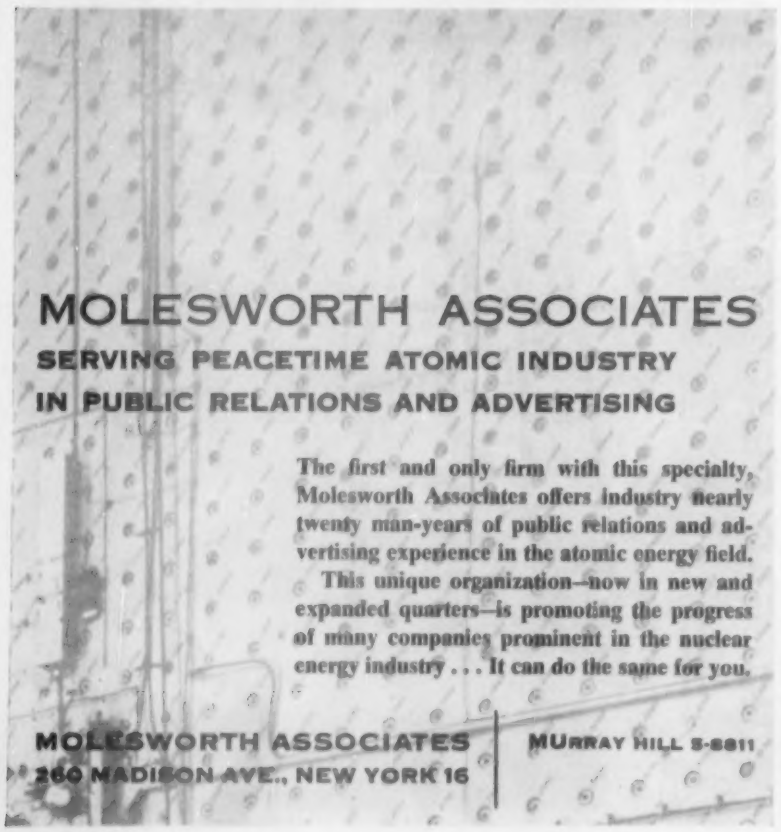

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on the end of the 6292 tube with balsam, which acted as both a light pipe and a cement. One-mil-thick aluminum foil was used to cover the crystal and the bottom of the 6292 tube, to improve light-gathering efficiency of the tube.

The crystal was fitted into coaxial holes in lead and copper shields. A slide for positioning the specimen under the hole in the copper shield is controlled by an indexing device that determines the traverse angle with respect to a reference point on the specimen and a 25-mm micrometer that establishes the specimen's position along the traverse.

During the experiments,† the photomultiplier was connected to a cathode-follower preamplifier. The preamplifier drove a short cable that was connected to a model 1060 Atomic Scaler. This arrangement was very satisfactory, but any scaler with desired response characteristics would suffice.

With the above method, it was possible to recheck readings with deviation from the average of less than ±6%. A high degree of collimation was achieved. On taking a reading at the outer edge of the Cu^{64} source, and then adjusting the micrometer to move the center of the hole in the copper shield 1.25 mm away from the edge of the source, the readings dropped almost to the background.

It is believed that this instrument offers a satisfactory procedure for studying movement of radioactive atoms over a surface. It is easy to make and simple to operate. The thickness of the shields, and dimension and type of crystal would naturally be determined by the energy and type of radiation emitted by the atoms being studied.

TECHNICAL BRIEFS

Radioactive plastic dissolves in body. Radioactive plastic needles and sutures that dissolve slowly in body fluids for localized cancer therapy were reported by H. C. Dudley and T. G. Mitchell (U. S. Naval Hospital, St. Albans, N. Y.) at the ACS 127th national meeting. Untried in human patients, plastic dissolves in less than two days, depositing radioyttrium, which delivers 100,000–170,000 r/gm of tissue. Yttrium oxide, irradiated in a reactor for 7 days, is mixed with methyl cellulose, a solvent—propylene glycol—formed into a soft pellet, extruded, and dried in an oven to form a rigid, 0.06-in.-

diameter filament. Part of the research was conducted at the BNL Medical Division.

Also reported at the meeting by Dudley and J. Greenberg of the Naval Hospital was a method of treating bone cancer with radioyttrium. Yttrium, combined with *N'*-hydroxyethylenediaminetriacetic acid, accumulates in growing bone tissue and avoids the marrow. This technique has only been applied to laboratory animals.

Measuring absolute flux through membranes. Tracer movement may not indicate absolute flux of a substance through a membrane, according to C. Edwards and E. J. Harris, University College, London (*Nature*, Feb. 5, 1955, p. 262). In measuring the flow in both directions across a membrane by putting a tracer on one side, anomalous results are sometimes obtained; the rate of movement per unit difference of concentration of isotopic water is sometimes less by a factor as high as 50 from the rate of movement resulting from a unit difference of water concentration imposed by the presence of dissolved salts. The suggestion is that if the membrane is several times as thick as the traversing molecule (x or x'), a file of molecules (xxx) may exist in a narrow pore. Collision of an x' on one side can lead to file $x'xx$, with displacement of an x to the other side. Another collision can restore file xxx. Although one unit is involved in each collision, no tracer has passed. Only when the membrane is thin enough so that a file does not form can tracer movement be proportional to the flux.

Distilling I^{131} from irradiated TeO_2. Dry distilling I^{131} from irradiated tellurium dioxide offers several advantages, according to Kjell Taugbøl and Knut Samsahl (Joint Establishment for Nuclear Energy Research, Kjeller, Norway): TeO_2 can be used repeatedly, giving extremely high specific activity; a minimum of reagents are needed; it is less time consuming; yield exceeds 90%. Since the distillation temperature is 650–680° C, TeO_2 was selected since its melting point is 735° C. TeO_2 as a fine powder showed a tendency to sinter above 600° C; this was overcome by allowing the precipitate to stand in the mother liquor for some hours before filtering; the larger crystals do not affect the distillation rate appreciably. The distilling apparatus is mainly quartz. Distillation is 2–4 hr at 2×10^{-2} mm.

Cary / instrument abstracts

Applied Physics Corporation/Pasadena/California

Radioactivity Measurements Made Faster, Cheaper with Vibrating Reed Electrometer

Pasadena, Calif. — Measurement of radioactivity in radioisotope determination, reactor control, air contamination studies, oil well logging, and other problems involving precise measurement of small currents, voltages and charges, such as precise pH determination and mass spectrometry, can now be made faster, simpler and cheaper by using the Cary Model 30 Vibrating Reed Electrometer.

Unusually high sensitivity plus high zero stability and ease of installation and operation are responsible for the greater speed and savings. The Model 30 detects as little as 10^{-17} amperes, and measures up to 10^{-6} amperes with a precision of 1%. Zero drift is less than 0.2 mV in 24 hours and less than .02 mV per hour.

C¹⁴, H³ DETERMINATIONS SIMPLIFIED

One widespread application in which the Model 30 has been of particular value is in determining C^{14}, H^3, and S^{35}. Wilzbach and his coworkers at Argonne National Laboratory have developed procedures* which simplify these determinations in a wide variety of organic compounds. Samples are converted directly to a gas suitable for measurement with an ionization chamber and the Model 30. This simple procedure eliminates the necessity for use of a precipitate, with its inaccuracy and time-consuming, tedious preparation.

Since as little as 10^{-12} curies of radioactivity can be detected, use of expensive "tagged" materials can be greatly reduced, often enough to return the cost of the instrument in a relatively short time.

The Model 30 can be used in any laboratory and does not require costly, vibration-free mountings or other special conditions of installation or operation. For additional information on the Model 30, write for bulletin N-1 today. It gives you details on applications, references, performance, operating principle, specifications, modifications, accessories.

*Wilzbach, Brown, Kaplan, Science, 118, 522-523 (1953)
Wilzbach, Van Dyken, Kaplan, Anal. Chem. 26, 880 (1954)
Wilzbach, Sykes, Science 120, 494-496 (1954)

The Cary Model 30 Vibrating Reed Electrometer is capable of detecting a current as small as 1.0×10^{-17} amperes originating in a high impedance source. Charges as small as 5×10^{-16} coulombs and voltages as small as .02 mV can be measured.

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One important application of the Model 39, for example, is its use with the Model 30 Electrometer to accurately measure very small currents by the rate of charge method over extended time intervals. Additional information on the Model 39 is provided in the bulletin described above.

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Temperature Measurements in JEEP

By ARNE LUNDBY
Joint Establishment for Nuclear Energy Research
Kjeller, Norway

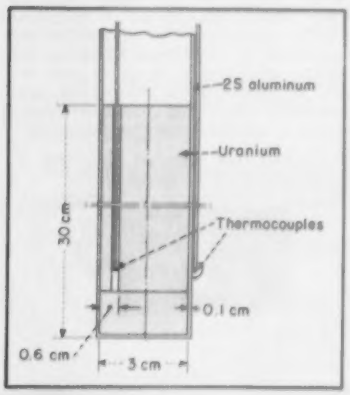


FIG. 1. Location of thermocouples in special fuel rod

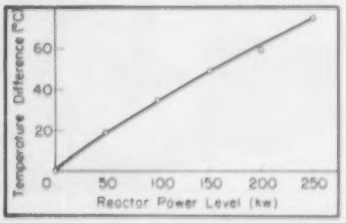


FIG. 2. Temperature difference between U and D_2O 38 cm from center of reactor

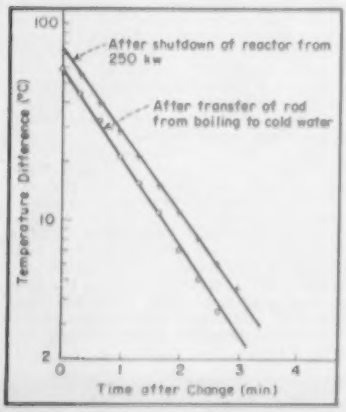


FIG. 3. Decay of temperature difference between uranium and water

Studies of thermal characteristics of JEEP show that the thermal resistance between the uranium fuel and the aluminum canning is rather large. At 250 kw (about 2.5 watts/cm² heat flowing through the surface of a central uranium rod) the maximum temperature difference is about 90° C.

How temperature variations affect the reactor's kinetic behavior also has been studied. Temperature coefficients for the uranium and the heavy water are: $\alpha_U = -1.5 \times 10^{-4}$/°C; $\alpha_{D_2O} = -25 \times 10^{-4}$/°C.

Experimental Arrangement

Figure 1 shows the special fuel unit used to make temperature measurements in the uranium. The fuel elements in the reactor consist of two uranium metal rods 2.54 cm in diameter and 190 cm long mounted together with a distance of 4 cm between their axes (*1*). The rods are built up of six 30-cm-long slugs stacked into 2-mm-thick 2S aluminum tubes. Both in the present experimental arrangement and in the reactor, the uranium was forced into the aluminum tubes. No further attempt was made to insure good thermal contact between uranium and aluminum. Thus, similar temperature distributions can be expected in the two cases, although minor differences undoubtedly will occur.

The thermocouples consisted of Alumel-Chromel wires silver-soldered together and mechanically attached to the uranium and aluminum by forcing the junctions between two pieces of the metals. The thermocouple wires were connected directly to a Brown recorder. The calibration curve for the thermocouples obtained by immersing them in a water bath show their sensitivity was 40 μv/°C.

Measurements

The special rod unit was lowered through a hole in the reactor top and was 38 cm from its axis. The middle of the rod was approximately in the median plane of the reactor. The slow-neutron flux, and thus the uranium temperature, at this position was about 10% lower than at the central axis.

Stationary conditions. Figure 2 shows the observed temperature differences. The D_2O temperature was measured both with a thermocouple and with resistance thermometers. The measurements are in error by 1 or 2°. Since there is a maximum temperature gradient from the center to the surface of the uranium of about 7–8° C at 250 kw, and the temperature in the center of the reactor is about 10% higher than those observed, the maximum uranium temperature above that of the heavy-water is about 90° C at 250 kw.

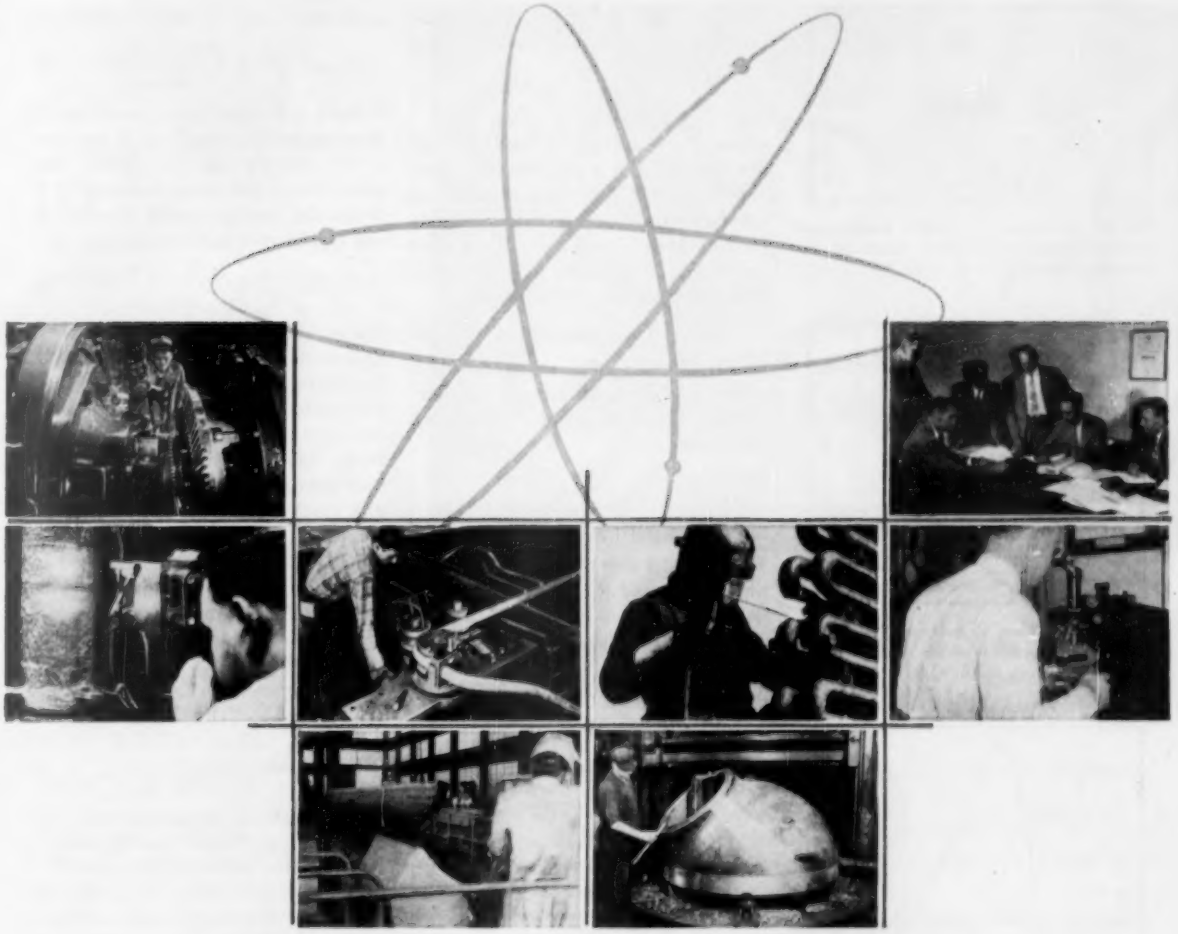
The aluminum temperature differed by only a few degrees from the average temperature of the heavy water. At 100 kw this temperature difference was about 3.5° C without the cooling system operating. When the cooling system was running the difference was less than 3° C. However, these figures vary according to the position in the reactor.

Transient conditions. When the reactor had been stabilized at 250 kw and the control rods suddenly inserted, the power level decreased to a few kw in a few seconds. The decay of the uranium temperature above the heavy-water temperature followed the upper curve in Fig. 3. The same decay rate was observed when the uranium rod was first heated in boiling water and then transferred to cold water.

To learn the reactor's dynamic behavior, the reactivity was suddenly increased and the consequent variations in power and temperature were followed as shown in Figs. 4–7. Reactivity was increased by shifting a control plate. The reactivity was determined by following the initial rise in power and making use of the doubling-time:reactivity relationship.

Interpretation

When the reactor is running at a certain power level W more than 90% is developed as heat transmitted from the



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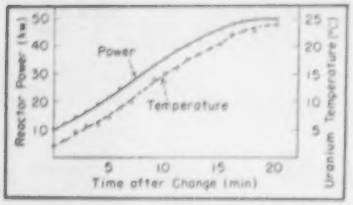


FIG. 4. Variations in reactor power and uranium temperature after suddenly increasing reactivity by 4×10^{-4}

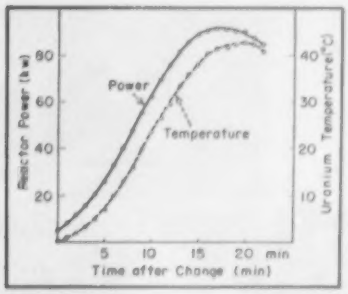


FIG. 5. Variation in reactor power and uranium temperature after suddenly increasing reactivity by 8×10^{-4}

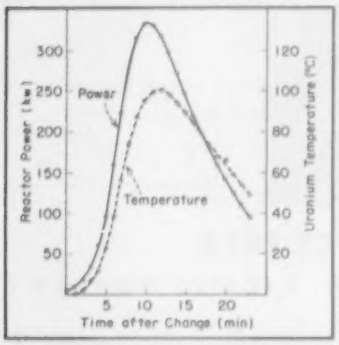


FIG. 6. Variations in reactor power and uranium temperature after suddenly increasing reactivity by about 10^{-3}; cooling system not operating

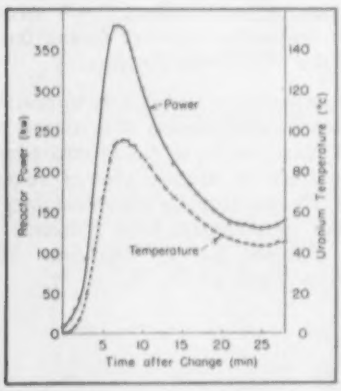


FIG. 7. Variations in reactor power and uranium temperature after suddenly increasing reactivity by about 10^{-3}; cooling system operating

uranium fuel elements through the aluminum to the heavy water. Thus

$$C_U \frac{dT_U}{dt} + \frac{A(T_U - T_{D_2O})}{R_{U-D_2O}} = W_h \quad (1)$$

where T_U = average temperature of uranium, T_{D_2O} = average temperature of heavy water, C_U = heat capacity of uranium rod, R_{U-D_2O} = thermal resistance between U and D_2O, W_h = heat production in uranium, A = U surface area. For stationary conditions

$$A(T_U - T_{D_2O})/(R_{U-D_2O}) = W_h \quad (2)$$

In Fig. 2, $T_U - T_{D_2O}$ is plotted as a function of W. At 250 kw the heat developed in the experimental fuel unit was about

$$W_h = (230 \times 10^3 \text{ watts})/(2.2 \times 10^3 \text{ kg}) \\ 4 \text{ kg} \times 1.5 = 630 \text{ watts.}$$

There are 2.2 tons of uranium metal in the reactor, and the fission rate in the central uranium rods is about 1.5 times the average fission rate in the uranium. Thus

$$R_{U-D_2O} = 76^\circ \text{ C } 289 \text{ cm}^2/630 \text{ watts} \\ = 35 \text{ °C/cm}^2/\text{watt} \quad (3)$$

From Fig. 2 it is seen that the thermal resistance between uranium and water decreases somewhat as the temperature of the uranium increases. This is probably mainly due to thermal expansion of the uranium. Temperature of the aluminum canning does not increase much as power increases.

Response to sudden removal of heat source. If the power level is suddenly reduced to zero, we have

$$C_U \frac{dT_U}{dt} + \frac{A(T_U - T_{D_2O})}{R_{U-D_2O}} = 0 \quad (4)$$

or

$$\frac{T_U - T_{D_2O}}{T_{U_0} - T_{D_2O}} = \exp\left(-\frac{At}{C_U R_{U-D_2O}}\right) \quad (5)$$

where T_{U_0} is the initial temperature of the uranium and T_{D_2O} is assumed constant.
With

$$C_U = (0.028 \text{ cal/°C/gm})(4 \times 10^3 \text{ gm}) \\ (4.2 \text{ watt sec/cal}) \\ = 4.7 \times 10^2 \text{ watt sec/°C} \quad (6)$$

we get from Eqs. 3 and 6

$$C_U R_{U-D_2O}/A = 57 \text{ sec} \quad (7)$$

Eqs. 5 and 7 agree with the observed decay of the uranium temperature after the power was shut off, or when the uranium rod was transferred to cold water after being heated in boiling water.

Heating of water. If C_{D_2O} is the heat capacity of the heavy-water moderator, and if this is stationary

$$C_{D_2O} \frac{dT_{D_2O}}{dt} = \frac{A(T_U - T_{D_2O})}{R_{U-D_2O}} \quad (8)$$

if right side now refers to all the U. Heat capacity of the D_2O in the tank is 3×10^4 kw sec/°C. Thus, with about 9 kwh the water is heated 1° C. When the cooling system is operating and stationary conditions prevail

$$C_{D_2O}' \Delta T_{D_2O} = \frac{A(T_U - T_{D_2O})}{R_{U-D_2O}} \quad (9)$$

where C_{D_2O}' is the heat capacity of the coolant flow and ΔT_{D_2O} is the increase in temperature by its passage through the reactor.

At 250 kw the temperature difference in the D_2O at the inlet and outlet of the heat exchanger is about 10° C. The flow rate is about 4 l/sec. Thus we find $C_{D_2O}' \Delta T_{D_2O} = 190$ kw. The remainder of the heat is removed by the air cooling of the tank and reflector and heat losses to the surroundings. The 190 kw figure is inaccurate by 10–20%.

Similarly, for the light water (*1*) in the secondary circuit of the heat exchanger, $\Delta T_{H_2O} = 17.4^\circ$ C at 2.6 liters/sec, and then $\Delta T_{H_2O} C_{H_2O}' = 190$ kw.

Temperatures in and around rods. The maximum temperature gradient in the uranium amounts to about 8° C from center to surface at 2.5 watts/cm² (250 kw). The temperature drop from the uranium to the aluminum is about 75° C in this case. The aluminum temperature is only a few degrees above the average temperature of the D_2O. According to Gilliland (*2*) the heat transfer coefficient for water under natural convection can be 0.17 watts/cm²/°C. Thus, for 2.5 watts/cm² the temperature gradient in the water should be 14–15° C. However, a much lower value (~5° C) was observed when the cooling system was operating. Thus, it seems that the circulation of the tank's D_2O is much more vigorous than pure convection can account for.

Temperature coefficients. The results in Figs. 4–7 can be interpreted if we know the temperature coefficients of the uranium and the D_2O.

If the excess reactivity at any time is k_{ex}, and

l = average lifetime of a neutron in the reactor,
c_i = density of the ith delayed neutron emitter normalized in a suitable way,
β_i = ratio of the number of delayed neutrons of mean life τ_i to the total number of neutrons emitted

in fission, then

$$\frac{dW}{dt} = \frac{k_{ex}}{l} W - \sum_i \frac{dc_i}{dt}$$
$$\frac{dc_i}{dt} = \frac{\beta_i}{l} W - \frac{c_i}{\tau_i} \qquad (10)$$

where

$$k_{ex} = k_{ex_s} - \alpha_U T_U - \alpha_{D_2O} T_{D_2O} \qquad (11)$$

and k_{ex_s} is the sudden increase in the reactivity and α_U and α_{D_2O} are the temperature coefficients of the uranium and D_2O, respectively.

By assuming $\alpha_U = -1.5 \times 10^{-5}$/°C, $\alpha_{D_2O} = -25 \times 10^{-5}$/°C, and using Eqs. 1, 10, and 11, the shape of the curves in Figs. 4–7 have been reproduced. These values of the temperature coefficients also agree with the results from other heavy-water reactors (*3*).

BIBLIOGRAPHY

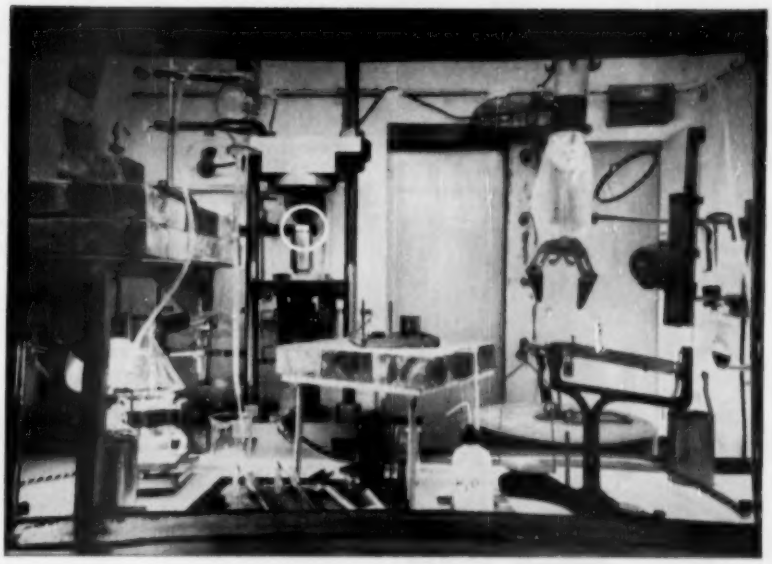
1. O. Dahl, G. Randers, NUCLEONICS **9**, No. 5 5 (1951)
2. E. R. Gilliland in "The Science and Engineering of Nuclear Power," vol. 1, chap. 10, p. 323, Clark Goodman, ed. (Addison-Wesley Press, Inc., Cambridge, Mass., 1949)
3. A. Ertaud, R. Beaugé, H. Faques, I. Vautrey, *J. Phys. Radium* **12**, 17A (1951)

REACTOR FACTS

More steps taken to insure reactor safety: fast breeder reactor and water boilers to be put through safety paces. With the first experiments to start soon, North American Aviation has been made responsible for testing a small water-boiler reactor of the type planned for university research. Object is to determine maximum amount of excess reactivity that safely can be introduced into such a reactor and the mechanism of self-regulation involved. Information is urgently required for two proposed research reactors. Test site has not been decided upon.

For safety tests on the fast breeder reactor, the new facility at the National Reactor Testing Station (NU, March 1955, page 10) probably can be used if large inventories of plutonium are not involved. Plans are still incomplete.

More low-power reactors needed. While the Army Package Power Reactor will meet the most urgent requirement (for reactors between 1 and 2 Mw), AEC says the defense department needs reactors to produce power in the range from a few hundred kw to 40 Mw. The Rural Electrification Administration also has expressed strong interest in small power plants to fill needs in outlying high-power-cost areas.



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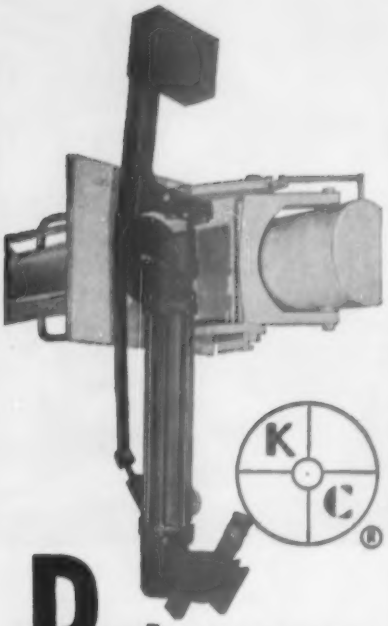

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TECHNICAL ADVANCES

Lattice Defects and Radiation Damage The number of lattice defects produced by nuclear bombardment is basic to mechanistic theories of radiation damage. Direct measurement by neutron scattering of the number of Frenkel defects (vacancies plus interstitial atoms) and improved agreement between experiment and theory were among the advances revealed at the Baltimore meeting of the American Physical Society.

Using a beam of neutrons of wavelength greater than Bragg cutoff, Brookhaven researchers Antal, Weiss, and Dienes were able to measure absolutely the attenuation due to scattering by lattice defects alone. For a graphite sample previously exposed to $10^{20} \pm 30\%$ neutrons/cm^2 it was found that $2.5 \pm 0.2\%$ of the atoms had been displaced, assuming randomly located defects. They used graphite itself to filter out the short-wavelength neutrons by crystalline Bragg scattering.

On the theoretical side, the problem has been determining the number of secondaries displaced by a struck primary atom (computation of the number of primaries is simple enough). W. A. Harrison and F. Seitz reviewed recent work that reveals the number of progeny per primary displaced atom as being about 5 for atoms bound in a 25-ev-square-well lattice. (This number is fairly independent of the energy of the primary.) Furthermore, evaluation by F. J. Blatt of the relation between change in resistivity and numbers of defects indicates that previous interpretations of radiation-induced resistivity changes had overestimated the number of defects. The lowered experimental values and raised theoretical values are now within a factor of 2 or 3 of each other. In particular, the Brookhaven graphite experiment mentioned above fits the theory within the combined experimental errors.

Intercomparison of Radium Standards Radium standards need to be especially accurate since they are used for direct-comparison assay of expensive radium sources. Recently the U. S., Canadian, and British standards were intercompared in Washington. The result relieved concern caused by apparent 1–2% disagreement implied by a 1949 comparison of secondary standards—the Canadian standard required upward adjustment by 0.5%, but the American and British standards are considered consistent to within 0.1%.

Labeling Compounds in a Reactor A technique for labeling complex organic molecules that promises practical application in supplying labeled compounds for research has been developed by A. P. Wolf and R. C. Anderson (Brookhaven chemistry department). Involving neutron irradiation in a reactor, this method permits labeling a specific position in the molecule, which cannot be controlled in biosynthesis, and enables the labeling of complex molecules that are difficult or impossible to produce by chemical synthesis.

Thus far, principal attention has been given to C^{14} labeling, using the $N^{14}(n,p)C^{14}$ reaction. Only materials in the solid state have been irradiated, although liquid-state applications will be studied.

Two approaches have been satisfactory—either the nitrogen homolog of the desired C^{14}-labeled compound or a mixture of the compound and another nitrogen-containing material have been irradiated. An example of the former was production of anthracene-C^{14} by neutron irradiation of the nitrogen homolog, acridine. The recoiling C^{14}'s of the (n,p) reaction were also found in acridine molecules, where the nitrogen had not undergone neutron capture. The ratio of activity as acridine to the activity as anthracene was about 19:1.

The second approach was applied in labeling nicotinamide by mixing it with acridine as the nitrogen source. Labeled nicotinamide was recovered 95% pure; impurities included products of the breakdown of the complex molecules. In this type of reaction, the energetic C^{14} produced in the nitrogen supplier displaces a carbon in the compound to be labeled. Although it is not yet fully understood why the labeled position is specific, it is believed to be at least partly determined by the bond energy of the displaced atom.

Two lead brick size 2" x 4" x 8" – one cast in an open mold (right), the other extruded through a die in a hydraulic press (left)—were sawed in half lengthwise, to show internal structure. After planing and buffing, the halves were photographed. The photos were retouched to kill highlights and achieve uniform tone on both brick. The sink and shrink-hole were not touched.

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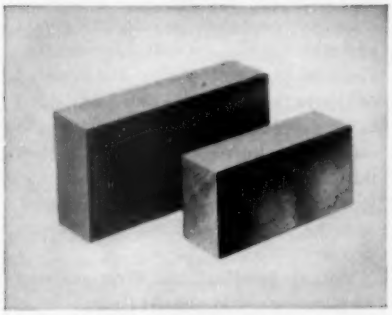

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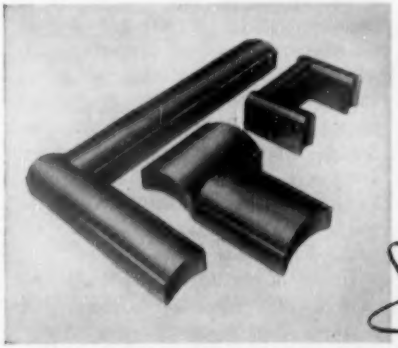

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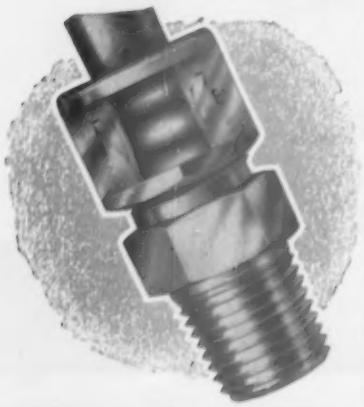

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BOOKS

Mass Spectrometry

By A. J. B. ROBERTSON (Methuen's Monographs on Chemical Subjects, John Wiley & Sons, Inc., New York, 1954, iv + 135 pages, $2.00). Reviewed by C. R. BALDOCK and C. P. KEIM, Oak Ridge National Laboratory, Oak Ridge, Tenn.

This useful contribution on mass spectrometry consists of only six chapters, a total of 120 pages. The presentation is brief but on the whole quite adequate, obviously having been prepared by one well versed in mass spectrometry.

Following a historical introductory chapter, the real heart of the book is contained in the second and third chapters. One chapter covers the principles and operation of the mass spectrometer, the other discusses the ionization and dissociation of molecules from electron bombardment. Both chapters are complete, lucid, and clearly understandable.

There is no reference to the theoretical work of Rosenstock, Wallenstein, Wahrhaftig, and Eyring (*Proc. Nat. Acad. Sci.* **38,** p. 667, August, 1952). Also, we expected to find reference to "Methoden und Anwendungen der Massenspektroskopie," by Heinz Ewald and Heinrich Hintenberger.

We note the absence of any reference to a good technique for solids analysis (see C. M. Stevens, M. G. Inghram, Ratio recording in isotopic analysis, *Rev. Sci. Instr.*, October, 1953, p. 987–9.) We think the importance of the stable-isotope-dilution method of analysis justifies more than a single paragraph.

We consider this monograph essential to anyone engaged in mass spectrometry.

Radioisotope Conference, 1954, Vols. 1 and 2

Edited by J. E. JOHNSTON, R. A. FAIRES, and R. J. MILLETT (Academic Press, New York; Butterworths Scientific Publications, London, 1954; Vol. 1: ix + 223 pages, $10.80; Vol. 2: xi + 418 pages, $7.50; both volumes: $16.00). Reviewed by PAUL C. AEBERSOLD, Isotopes Division, U. S. Atomic Energy Commission, Oak Ridge, Tenn.

This conference was sponsored by the Atomic Energy Research Establishment, Harwell, England. Volumes 1 and 2 of the proceedings are well-prepared compilations of the 70 timely papers on medical and physiological applications of radioisotopes and on physical science and industrial applications, respectively.

The conference committee in charge of selecting a program from 280 candidate papers is to be commended for giving preference to new ideas and important new results. Because they did so, the books present a useful picture of the "present state of the art," of the advanced type of thinking being applied to problems in radioisotope usage, and of the developments that are just around the corner.

This effort to present timely material would be largely wasted, as far as nonconference goers are concerned, if the usual 10 or 12 months elapsed before it reached them. The editors of this book are therefore to be commended, in turn, on succeeding with their plan to get it out within 3 or 4 months. Errors that may occur, because the delay attending final author review was avoided, are not apparent. They must be few, if any, because of the care taken in having all remarks, even during question periods, written out on forms provided for the purpose.

Most of the papers, of course, are British and give a clear picture of the radioisotope's importance in biology and industry in England. Ten other European countries, as well as Canada and the U. S., are also represented, emphasizing the fact that the benefits of the radioisotope are being extended to all people. Although parallel paths seem to be taken during the ventures into new territory, different groups, whether in the same or a different country, develop different approaches and techniques.

Vol. 1: Medical and Physiological Applications. While old enough to be well established, the use of radioisotopes in medicine and physiology, as shown by the 46 papers in Vol. 1, is still new enough to be a rich field for discoveries and development. Advances in instrumentation accelerate this development and are represented here by the scintillation counter plus double-discriminator pulse analyzer. Increased precision in brain tumor localization and detailed outlining of the thyroid and other organs are realized with this device.

In one of the interesting studies reported, the I^{131} activity in saliva, after a tracer dose, is correlated with thyroid function; the hypothyroid patients showed about 20 times as much

activity as hyperthyroids. Fe^{59} was used in clinical studies of various diseases affecting the bone marrow; uptake in various organs and plasma clearance rates are indicative, in each case, of the particular impairment. The supremacy of I^{131} and Au^{198} in some therapies is being challenged by preliminary work with At^{211} and Y^{90}. Bi^{206} is introduced as a "short-lived radium" for interstitial injection, and radiogold on charcoal is being tried in large-particle therapy for selective deposition in areas of the lung.

The section on animal physiology and pathology comprises 13 papers that, as a whole, give an up-to-date picture of this area. A method is described by which cardiac output is determined from the pattern of activity over the heart after a "slug" of radioisotope enters a vein. In a similar technique in this country, the pattern of activity in a distant artery is thought to give a more clear-cut result. By introducing blood cells labeled with P^{32} into an animal at one point in a reported experiment and with Cr^{51} at another point, direct evidence was obtained for the theory that, in the state of shock, an appreciable fraction of the blood ceases to circulate.

The 15 papers grouped under biochemistry bear witness to the growing importance of radioisotope-labeled compounds wherever life processes are studied. The labeling of thyroxine with I^{131} is described and the factors influencing its assay by radiochromatography, and that of triiodothyronine in plasma after an I^{131} dose, are discussed. Whereas radioactive guinea-pig serum in quantities less than 50 μg refused to migrate in paper electrophoresis, it is reported that an addition of concentrated human serum prevented the absorption but did not impose its own migration rate upon the guinea-pig serum. The human-serum method was extended to other trace proteins. Since extremely small quantities of I^{131}-labeled insulin were thus detectable, a detailed study of the distribution of injected insulin in the rat was possible.

Asymmetric labeling in the synthesis of C^{14}-glycogen from C^{14}-glycerol in rat liver is described and an attempt is made to account for it. Antigen-antibody relations were studied using I^{131}-labeled horse gamma globulin and other antigens in normal and immune rabbits.

These few papers have not been selected for mention here as the most

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As every schoolmaster knows, pupils are from time to time capable of the most learned dissertations on subjects completely outside the matter in hand. Not, it should be added, that these often concern such specialised subjects as Linear Amplifiers. To be put fully in the picture on this it is necessary to talk to EKCO, who have all the relevant details at their finger-tips.

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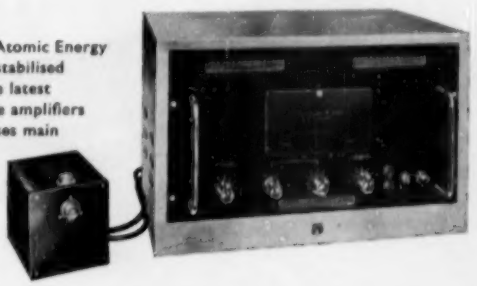

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interesting or important but rather as an indication of the range of subjects covered.

Vol. 2: Physical Sciences and Industrial Applications. Volume 2 of the conference proceedings comprises 24 papers on radioisotope uses in nonmedical fields, equally up-to-date with those in Volume 1. The chemistry section leads off with a tracer study of the mechanism in polymerization and the structure of polymers. Then, a method for measuring diffusion coefficients under conditions of constant chemical composition is given, taking note that diffusion coefficients of solutes in high polymers change very rapidly with changing concentration. Meticulous work with C^{14} is reported in investigating the Wagner-Meerwein rearrangement involving 1,2,2-triphenolethanol and its derivatives, and various aspects of the ring labeling of compounds are discussed. The role of radiation in the exchange reaction between iodine and methyliodide, and that of oxygenated radicals in the Fischer-Tropsch reaction, are clarified.

The chemistry and metallurgy section ranges from a radioisotope study of poisoning in solid catalysts used in ammonia synthesis to careful measurements of coefficients of diffusion of copper and zinc into alpha and beta brass. The preparation of krypton-85 and tritium are described and a number of their interesting potential uses are discussed. The factors involved in the autoradiographic study of segregation in steel, and of the effect of heat treating and working on the rate of homogenization, are presented. The combination of tracers with radioactivation analysis is beautifully illustrated in work on the purification of aluminum from zinc, copper, sodium, and silicon by zone melting.

Several papers on applied physics are grouped under *Physics and Industrial Applications*. The assay of deuterium samples is described in which Na^{24} gamma rays release neutrons for the measurement. Soil moisture determination by neutron scattering is compared with other methods now in use. An extremely sensitive method for C^{14} counting is presented, as applied to archeological dating, in which the specimen is converted to acetylene as the counter filling gas. A second method dissolves the acetylene in a liquid phosphor for scintillation counting at −78° C. A thickness gage uses alpha radiation for measuring paper and acetate films in the range below

25 gm/m², while another uses back-scattered gamma rays to measure tube-wall thickness. The use of P^{32}-labeled wool fibers is described in a study of the difficult problem of drafting in wool spinning.

Papers from the final session are grouped under *Industrial Applications* and illustrate the down-to-earth, every-day practicality of the radioisotope. Tracer studies can give valuable data on flow-through and hold-up times in sewage settling tanks as well as on flow problems in general. The accuracy in tracer measurement of carbide-cutting-tool life is described. The use of radioactive sources for ionizing air in charge dissipation is discussed, along with an extension of the technique to blowing the ionized air into a room. Data are presented on Ce^{144} and Tm^{170} as potentially important gamma-ray sources in industrial radiography. The last paper describes the use of a kilocurie source in food sterilization and discusses the companion subject of great present-day interest, the initiation of chemical reactions by radiation.

Although omitting mention of numerous well established radioisotope uses, these books do a good job of presenting new ideas and new techniques. They should be of interest to potential as well as to experienced radioisotope users. Presenting considerable quantitative information on feasibility studies and the ultimate use of the radiomaterials in particular problems, the books are directed toward the technical reader in particular.

A summary of the conference, including brief abstracts of most of the papers, appears in NUCLEONICS, Oct. 54, p. 48, and provides an effective abstract of Vols. 1 and 2.

Multipole Fields

By M. E. ROSE (John Wiley & Sons, Inc., New York, 1955, viii + 99 pages, $4.95). Reviewed by HERMAN FESHBACH, Jefferson Physical Laboratory, Harvard University, Cambridge, Mass.

The electromagnetic field provides a sensitive and useful probe for investigating properties of the atomic nucleus. On the one hand, the fantastically precise magnetic resonance methods may be employed to determine the electric and magnetic properties of the nuclear ground state, such as magnetic moment, electric quadrupole moment, and recently even octupole magnetic moments, as well as associated mechanical properties such as spin. Information

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about excited states is furnished by gamma-ray lifetimes, internal conversion coefficients, angular correlation, and Coulomb excitation studies. It is to this last set of phenomena, in which gamma rays are either absorbed or emitted, to which the author addresses himself.

The first task he sets himself is to obtain expressions for the electromagnetic field that are in a form most suitable for quantum phenomena, i.e., one in which the angular momentum and parity of the electromagnetic field is most clearly exhibited. To this end, once a brief discussion of Maxwell equations, electromagnetic potentials and gage is disposed of in the first chapter, the author gives a brief discussion of the angular momentum operators and the associated rotation group, including such concepts as irreducible tensors, Clebsch-Gordon and Racah coefficients. It then becomes possible to construct solutions of the source-free Maxwell equations that have a given total angular momentum and parity.

The construction of these multipole fields and their properties are the subjects of Chapters 2 and 3. Chapter 4 treats the problem of Maxwell equations with sources. Here the necessary Green's function expansion is obtained and the introduction of multipole moments is made. In Chapter 5, internal conversion forms the main subject. Appropriate expansion of the plane electromagnetic wave is obtained. This chapter also devotes some attention to the question of gage, which has been a stumbling block for many who have worked in this field. In the last chapter, expressions for gamma-ray emission probabilities are obtained using the *j-j* coupling model for nuclei. The effect of exchange currents is discussed.

All this in 90 pages! The book is therefore a miracle of compactness, but as a consequence requires a considerable background on the part of the reader well beyond the usual introductory courses in quantum mechanics. For the research worker in nuclear physics, it provides an extremely useful source for both the understanding and application of the theory of the interaction of the electromagnetic field with the nucleus.

BOOKS RECEIVED

An Outline of Atomic Physics, 3rd edition, by Oswald H. Blackwood, T. H. Osgood, A. E. Ruark (John Wiley & Sons, Inc., New York, 1955, x + 501 pages, $7.50). *(To be reviewed.)*

Electrons, Atoms, Metals, and Alloys, by William Hume-Rothery (Philosophical Library, New York, 1955, $10.00). Written in a dialogue form, this book discusses the theory of metals in a very readable manner for the nonmathematical reader. Starting with elementary electron theory, it proceeds through dialogues on metals, alloys, and nuclear phenomena.

Elements of Servomechanism, by George J. Thaler (McGraw-Hill Book Co., Inc., New York, 1955, x + 282, $7.50). This book in the McGraw-Hill Electrical and Electronic Engineering Series, intended for the undergraduate level, covers loop systems and introduces multiloop systems. Operational calculus and complex-variable theory are not used in presenting the basic theory.

Science and the Human Imagination, by Mary B. Hesse (Philosophical Library, New York, 1955, 171 pages, $3.75). In the introduction, the author says: "In recent years study of the history and philosophy of science has tended to show that the historical relations of science need some reinterpretation . . . the author's hope is to contribute to a lessening of tension between the scientific and the Christian attitudes . . . but for the most part the following chapters are offered as a straightforward account of recent studies in the history and philosophy of science."

Advanced Mathematics for Engineers, 3rd edition, by H. W. Reddick and F. H. Miller (John Wiley & Sons, Inc., New York, 1955, xiv + 548 pages, $6.50). The mathematical procedures treated are differential equations, operational calculus, Fourier series, partial differential equations, vector analysis, elliptic integrals, gamma and Bessel functions, and functions of a complex variable; new material includes Legendre's equation, numerical methods, Laplace transforms, and reversion of power series.

ALSO OF NOTE

Nuclear Engineering Series. The forthcoming McGraw-Hill Series in Nuclear Engineering has as its consulting editor W. H. Zinn. On press is "Nuclear Reactor and Power Plant Control," by M. A. Schultz. In preparation are: "Nuclear Chemical Engi-

neering" (Manson Benedict, Thomas Pigford), "Radiation Shielding" (E. P. Blizard), "Nuclear Engineering" (Charles Bonilla and associates), "Nuclear Engineering Handbook" (Harold Etherington, editor), and "Reactor Theory" (David K. Holmes, R. V. Meghreblian). *McGraw-Hill Book Co., Inc., 330 W. 42nd St., New York 36, N. Y.*

Radioactive Materials and Stable Isotopes (Catalogue No. 3). Published in July, 1954, the catalog lists the isotopes and sources obtainable from Harwell, as well as information on their preparation, the advisory service, isotope school, health hazards, and sales conditions and transport. Available materials include pile-produced and cyclotron-produced isotopes, fission products, γ-ray radiographic and therapeutic sources, and neutron sources. *Isotope Information Office, Atomic Energy Research Establishment, Harwell, Nr. Didcot, Berks, England.*

Proceedings of the International Conference of Theoretical Physics. This conference was held in Tokyo, Sept., 1953, under the auspices of the International Union of Pure and Applied Physics, supported by UNESCO and the Rockefeller Foundation; 600 Japanese and 55 physicists from 13 other countries attended. The 970-page report contains lectures, discussions, and some informal meetings. *Kinokuniya Book Store Co., Ltd., 826 Tsunohazu 1-chome, Shinjuku-ku, Tokyo, Japan, $10.00 + $1.00 postage.*

Elegant versus Elaborate Network Calculations. The 4-page Monograph 1.1 describes use of the time-saving potentiometer method for steady-state and transient calculations. *Stockman Electronics Research Co., Dept. D8, 543 Lexington St., Waltham, Mass., $.20.*

Engineers' Job Directory. Directory gives facts about 129 companies of interest to engineers seeking jobs. *Decision, Inc., 105 E. Fourth St., Cincinnati 2, Ohio, $2.25.*

Medicine in the Atomic Age. The Nov., 1954, issue of "Medicine Illustrated" is devoted to *Peaceful Uses of Atomic Energy* and *Atomic Warfare—Medical Aspects.* Peaceful uses include diagnosis and therapy, together with a discussion of personnel protection and genetic effects. The warfare section includes a description of a fatal injury at Los Alamos. *John De Graff, Inc., 64 W. 23rd St., New York 10, N. Y.*

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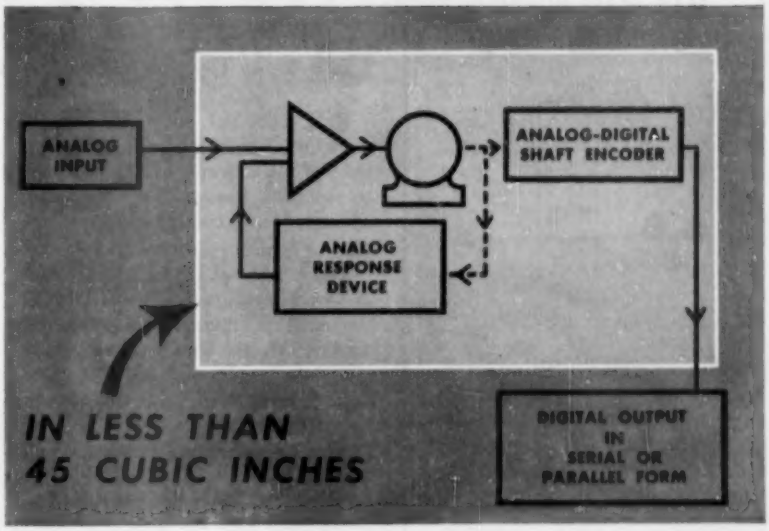
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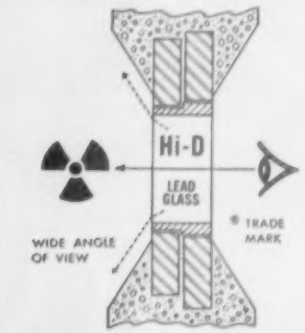

Hi-D Lead Glass Windows in concrete walls are dry, and hence are completely dependable. Where the viewing problem is mainly wide-angle vision, Hi-D Glass is fully competitive in price with zinc bromide.

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Model 107	Amplifier	$545.00
Model 107P	Amplifier (includes pulse-height selector)	$595.00
Model 112	Amplifier (gain of 1000)	$350.00
Model 401	Mercury Pulse Generator	$125.00
Model 515	HV Supply (500-1500 volts)	$385.00
Model 540	HV Supply (1000-4000 volts)	$535.00

(prices FOB Silver Spring)

RADIATION INSTRUMENT CO.
P.O. BOX 733 SILVER SPRINGS, MARYLAND

Patents

Slide-Rule Calculator for Disaster Radiation Monitoring

U. S. 2,699,894, issued to Abraham A. Hirsch, provides a slide-rule-type calculator that solves problems relating to radiation hazards likely to be encountered in monitoring following a nuclear bomb explosion (see Fig. 1).

The moveable sliding scale operates in two dimensions. The variable on the slide is instantaneous intensity reading; on the graph, time interval after the explosion (hr) and total dosage, with length of stay as the parameter.

As an example, to find the dosage knowing intensity at time of arrival and length of stay, align the right edge of the slide with the time after explosion on the graph and set the number 1 on the slide on the appropriate length of stay curve. Then, opposite the intensity value on the slide read the dosage from the corresponding horizontal line on the graph.

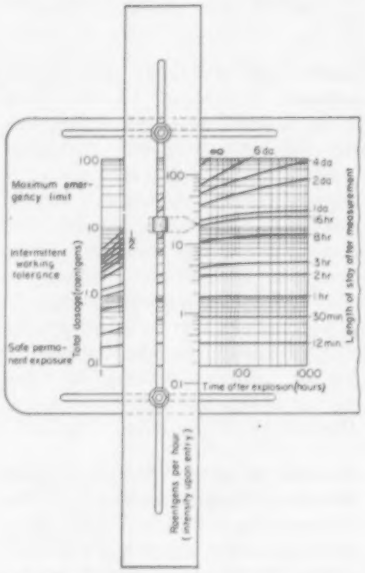

FIG. 1. Calculator for use in emergency monitoring

Radiation Meter Using Electron-Ray-Tube Indication

U. S. 2,696,563, issued to John H. Coleman and assigned to Radiation Research Corp., describes an instrument for measuring radiation that utilizes the deflection of an electron beam to indicate upon the screen of a electron-ray-type tube the radiation level without any mechanical indication.

Since different types of tubes vary in the magnitude and characteristic of control-element current, certain combinations of tube and radiation-sensitive element are best for particular radiation-intensity ranges. The 6E5-type tube connected in a balancing circuit covered a range with an ionization chamber of 100–100,000 mr/hr, having a grid current of 10^{-10}–10^{-11} amperes at balance. The range can be extended below 100 mr/hr by utilizing a G-M tube, which provides more current than the chamber, or by utilizing another class of cathode-ray tube, such as the 6AL7, which draws less grid current under certain operating conditions.

Not only does this method provide a wide meter range, but the instrument is more rugged than those types requiring mechanical indication, such as an ammeter or quartz-fibre electroscope, and permits simplified circuitry.

How to Measure Radiation with Electrets

U. S. 2,695,363, issued to Harry B. Marvin and assigned to General Electric Co., describes a method and apparatus for measuring ionizing radiations such as X-rays, γ-rays, β-rays, and α-rays by means of an electret.

Electrets are electrically insulating materials, e.g., carnauba wax and fluorothene, capable of retaining electric charges for long periods. The primary charge is due to an internal molecular rearrangement.

The apparent charge of an electret is reduced when the electret is exposed to

high-energy radiation. According to the inventor, this is not due to dissipation of internal charges but is primarily due to the attraction of ions produced by the radiation to the surface of the electret, where the ions produce surface charges that tend to neutralize the internal charges.

Thus one can measure radiations placing an electret within a container containing a fixed amount of ionizable air. The reduction in apparent charge of the electret is measured to determine the amount of ionizing radiation to which the container has been exposed.

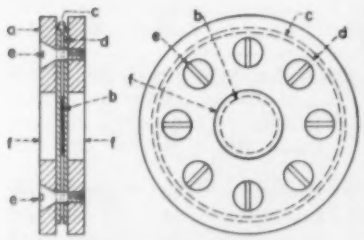

FIG. 2. Beta-ray source

Beta-Radiation Source

U. S. 2,700,111, issued to Robert B. Jacobs and Evon C. Greanias, and assigned to Standard Oil Co. (Ind.), describes a radioactive source that emits beta particles from two faces.

As shown in Fig. 2, the device consists of 0.062-in.-thick annular disks (a) having an outside diameter of 1.25 in. and an inside diameter of 0.375 in. The radioactive source (b) is deposited on a thin disk, such as gold leaf or mica. The base and cover sheets (c) are about 0.004 in. thick; the sheets are placed together with a polyethylene annulus (d) between the two sheets. The device is held together by screws (e). The entire unit is heated to about 400° F, causing the polyethylene to make a tight seal between the mica sheets.

This construction provides a uniform source of β-rays that are emitted in opposite directions through the windows (f).

The patent also describes a shutter mechanism for use with the source, and a jig used in depositing the radioactive material on the base sheet.

* * *

These descriptions are based on abstracts furnished by Melvin Nord, Registered Professional Engineer and Patent Attorney, Detroit, Mich.

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for Tritium Carbon-14 and Other Beta Emitting Isotopes

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Tri-Carb Spectrometers are currently in routine use in research and clinical laboratories in universities, government installations and industrial organizations. They are in regular production and are available for prompt delivery.

★ *This relatively new method of counting beta samples in solution with liquid phosphors is described in detail in Tri-Carb Bulletin 314.* History, basic principles, sample preparation and typical applications are all covered. Request your copy now.

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PRODUCTS AND MATERIALS

Portable Radiation-Shielding Materials

A | NUCLEONICS Special Report

THE MATERIALS LISTED in the table at the right are commercially available shielding forms that can be used to build readily assembled, hand-stacked shielding walls. NUCLEONICS queried all known suppliers of portable radiation-shielding materials and from their answers compiled the table. Other materials suitable for radiation shielding and suppliers of special shapes are given below, after mentioning some aspects of shielding-material selection.

Material selection. The desirable shielding material will depend on radiation energies present, shielding-material price and attenuation coefficient, appearance and hardness requirements, and shipping distance from the supply source. An item to be decided by each user individually is whether seam cracks can be tolerated. With flat bricks cracks will occur. A double layer, with seams staggered, eliminates seam leakage. The curved and sawtooth interlocked-brick suppliers claim that no seam leakage occurs with a single layer of their products.

Another item for each user to decide is how high hand-stacked walls may be built safely. Interlocked-brick suppliers claim a higher safe wall is possible with their products than with flat-surfaced bricks. For flat surfaced bricks, stability will vary according to the orientation of the bricks.

Often, when using portable shielding walls, skyshine—radiation reflected from above the source to in front of the shielding wall—is the greatest source of radiation leakage. To minimize skyshine, higher ceilings, higher shielding walls, and wood or aluminum ceilings rather than concrete are useful. Radiation shielding theory is too weighty a topic to present here, but useful information will be found in the bibliography (*1–7*).

Lead-impregnated plastics. Up to 95% lead content is claimed possi-

Supplier	*Nominal composition*	*Size: width × length × height (in.)*	*Type of joints—shape*	*Weight/unit (lb)*	*Cost ($)*
LEAD BRICKS $t_{1/10}$ = 1.40 in. for 1.25-Mev γ, 0.77 for 0.66 Mev, 0.30 for 0.35 Mev.*					
Ameray Corp., Kenvil, N. J.	Lead	4 × 8 × 2	Butt-A	26	On request
		4 × 8 × 2	Curved-B†	25	
Atomic Research Laboratory, 2633 St. Monica Blvd., St. Monica, Cal.	Lead-4% Sb	4 × 8 × 2	Butt-A	26	10.00–6.00‡
		4 × 4 × 2	Butt-A	13	7.00–4.00‡
	Lead-pure	4 × 8 × 2	Butt-A	26	10.00–6.00‡
Bar-Ray Products, Inc., 209 25th St., Brooklyn 32, N. Y.	Lead	4 × 8 × 2	Curved-B†	26	about 7.50
		4 × 8 × 2	Butt-A	26	about 7.00
		2 × 6 × 3	Curved-B†	15	about 4.50
		2 × 6 × 3	Butt-A	15	about 4.00
Belmont Smelting and Refining Works, Inc., 330 Belmont Ave., Brooklyn 7, N. Y.	Virgin lead	4 × 8 × 1	Butt-A	12.5	2.50¶
		4 × 8 × 2	Butt-A	25	5.00§
	Commercial lead-99%	4 × 8 × 1	Butt-A	12.5	2.39¶
		4 × 8 × 2	Butt-A	25	4.78§
Detectolab Inc., 6544 Sheridan Rd., Chicago, Ill.	Lead	4 × 8 × 2	Butt-A	26	13.00
Division Lead Co., 7742 W. 61st Pl., Summit, Ill.	Lead-99.98%	2 × 4 × 4	Sawtooth-C†	13.2	On request
		4 × 8 × 2	Butt-A	26	
Isotopes Specialties Co., 3816 San Fernando Rd., Glendale 4, Calif.	Lead	4 × 8 × 2	Butt-A	26	On request
National Lead Co., 111 Broadway, New York 6, N. Y.	Lead-99.90%	2 × 6 × 3	Curved-B†	14.55	On request
		4 × 8 × 2	Curved-B†	25.25	
		6 × 8 × 2	Curved-B†	39.00	
		2 × 6 × 3	Butt-A	19.68	
		4 × 8 × 2**	Butt-A	26.24	
NRD Inst. Co., 6425 Etzel Ave., St. Louis 14, Mo.	Lead	4 × 8 × 2	Butt-A	26	9.20
		2 × 6 × 3	Curved-B†	14.5	5.00
		4 × 8 × 2	Curved-B†	26	9.60
Nuclear Inst. and Chemical Corp., 223 W. Erie St., Chicago 10, Ill.	Lead	2 × 4 × 4	Sawtooth-C†	14	7.00
		4 × 8 × 2	Butt-A	26	11.00

Supplier	Nominal composition	Size: width × length × height (in.)	Type of joints—shape	Weight/unit (lb)	Cost ($)
LEAD BRICKS (*Continued*)					
Radiation Counter Laboratories, 5122 W. Grove St., Skokie, Ill.	Lead	4 × 6 × 2	Butt-A	19.8	On request
Ray Proof Corp., 513 W. 54th St., New York 19, N. Y.	Lead	2 × 6 × 3	Curved-B†	14.5	5.00
		4 × 8 × 2	Curved-B†	25	7.50
		2 × 6 × 3	Butt-A	15	4.50
		4 × 8 × 2	Butt-A	26	7.00
		6 × 8 × 6	Sawtooth-D	118	40.00
R-C Scientific Inst. Co., 307 Culver Blvd., Playa Del Rey, Calif.	Lead	4 × 8 × 2	Butt-A	26	9.50
Tracerlab, Inc., 130 High St., Boston 10, Mass.	Lead-5% Sb	4 × 8 × 2	Butt-A	26	9.50
		1½ × 6 × 3	Tongue and groove-E†	12	7.50
IRON, STEEL BRICKS $t_{1/10}$ = 2.2 in. for 1.25-Mev γ, 1.6 for 0.66, 1.1 for 0.35.*					
Atomic	Iron-coated	4 × 8 × 2	Butt-A	12	4.00
Detectolab	Iron	4 × 8 × 2	Butt-A	17	35.00/10
Isotopes Specialties	Steel	4 × 8 × 2	Butt-A	17.5	On request
Radiation Counter	Iron	4 × 6 × 2	Butt-A	13.3	On request
BAGGED IRON SHOT $t_{1/10}$ = 9.85 in. for 1.25-Mev γ.*					
The Master Builders Co., 7016 Euclid Ave., Cleveland 3, Ohio	Graded and ground iron (s. g. = 2.21)	14½ × 28 × 3 (packed in polyethylene-lined cotton bags)	Curved-side bag	100	8.75
		9 × 16 × 3	(see above)	35	3.06
MARBLE BRICKS $t_{1/10}$ = 5.77 in. for 1.25-Mev γ, 4.35 for 0.66.*					
Contact **Marble Institute of America,** 108 Forster Ave., Mt. Vernon, N. Y. for suppliers	White marble	4 × 8 × 2	Butt-A	6.3	0.85††
		4 × 8 × 4	Butt-A	12.6	0.85–1.00††
		4 × 8 × 8	Butt-A	25.2	1.50–1.80††
HIGH-DENSITY CONCRETE BLOCKS $t_{1/10}$ = 4.7–1.5 in. for 1.25-Mev γ, 3.5–1.1 for 0.66, 2.6–0.8 for 0.35.*					
Ray-Proof	Magnetite (s. g. = 3.4)	8 × 8 × 6‡‡	Sawtooth-D†	46.7	3.65
	Ferro-phosphorous, (4.8)	8 × 8 × 6‡‡	Sawtooth-D†	66.5	4.50

(*Table continues on next page*)

ble with a moldable lead-plastic compound sold by Telectro Industries, Inc., 35-16 37th St., Long Island City, N. Y. The maker says: Lead-cast has controllable hardness from that of a semi-rubber to that of cast aluminum; the metallic constituents can be any metal, mixture or compound; the material can be molded with any structural member with excellent bonding; the surface is inert to oxidation and corrosion.

Experimental quantities of a leaded plastic sheet stock are available from R-C Scientific Instrument Co. (see table for address). The density varies so the material is equivalent to from $\frac{1}{32}$ to $\frac{1}{8}$ in. of lead sheet.

Two types of leaded plastic are offered by Walbuck Crayon Co., Andover, Mass. One contains 94% lead and stays soft and pliable permanently. It is for room temperature and below uses. The other contains 90% lead. It can be set to a hard material by heating to about 300° F.

Other lead forms. Caster-mounted screens containing $\frac{1}{16}$ in. of lead are supplied by Ameray, Bar-Ray and Ray Proof. These firms also supply lead-containing paneling that may be of use.

Lead shot, from 0.04 to 0.38-in. in diameter is sold by Belmont. Price is 20.5–34.5¢ per lb, for 500-lb orders. National Lead also sells lead shot.

Special lead shapes are available from Ameray, Anchor Metal Co., (244 Boerum St., Brooklyn 6, N. Y.), Atomic Research Laboratories, Bar-Ray, Belmont, Canadian Radium and Uranium Corp., (630 5th Ave., New York 20, N. Y.), Division Lead Co., Federated Metals division of American Smelting and Refining Co., (120 Broadway, New York 5, N. Y.), National Lead, Radium Chemical Co., (161 East 42nd St., New York 17, N. Y.), and Ray Proof. Lead brick to specification is sold by many of these firms. The Lead Industries Association, 420 Lexington Ave., New York 17, N. Y., can supply names of other lead sources.

Knapp Mills, Inc., 23-15 Borden Ave., Long Island City 1, N. Y., offers specially designed shields made of lead-clad steel, copper, aluminum and stainless steel.

High-density alloys. Three manufacturers sell a high-density tungsten, nickel and copper alloy. Their products are sold as blanks, special

TABULATION OF PORTABLE SHIELDING MATERIAL *(Continued)*

Supplier	Nominal composition	Size: width × length × height (in.)	Type of joints—shape	Weight/unit (lb)	Cost ($)
HIGH-DENSITY GLASS BRICKS*					
Ameray	Lead glass	2 × 8 × 4	Steel frame-A	14	On request
Bar Ray	Lead glass (s. g. = 6.25)	2 × 8 × 4	Lead framed-A	14.5	120.00
Corning Glass Works, Standard Products Sales, Corning, N. Y.	Lead glass, type 8363 (s. g. = 6.2)	2 × 8 × 4 4 × 8 × 4 6 × 12 × 4 8 × 4 × 4§§	Lead or steel framed-A	14 29 67 28	On request
Fish-Schurman Corp., 70 Portman Rd., New Rochelle, N. Y.	Lead glass (s. g. = 5.13) (s. g. = 6.02)	Available to 40-in. square and 20-in. thick	Framing is available		On request (not a standard product)
Penberthy Instrument Co., 666 Adams St., Seattle, Wash.	Lead glass	4 × 8 × 4	Steel framed-A	32	144.00
Tracerlab	Lead glass (s. g. = 6.2)	4 × 8 × 4	Steel framed-A	30.5	175.00

* A tenth-value layer of material will reduce the original radiation intensity by a factor of 10. The figures for lead and iron are taken from Moteff (*5*). Other values were supplied by the manufacturer. The energies cited are the effective energies of Co^{60}, Cs^{137} and Ir^{192}. For the concrete bricks, the first figure applies to the lighter concrete, the second to the denser concrete. For shielding glasses, the attenuation factor—the ratio of radiation entering the material to radiation transmitted through the material—is as follows for the Corning products: 2-in. thick–6.1 for 1.25-Mev, 1.6×10^3 for 0.35, 4 in.–37 and 2.7×10^6, 6 in.–222 and 4.5×10^9, 8 in.–1,333 and 7.3×10^{12}. For Tracerlab glass the attenuation factor is 37 and 2.7×10^6. Ameray and Penberthy gave the lead equivalent of their glass as 0.55 in./in. of glass at 1 Mev.

† Enclosed shapes can be built-up from left- and right-hand corner bricks, male and female flat-end bricks, and male and female flat-end half-bricks, that are also sold.

‡ Lower prices are for quantity purchases.

§ Price applies to lots of 40 or more.

¶ Price applies to lots of 20 or more.

** Other shapes are also available, as dies for extrusion are at hand.

†† Prices apply to lots of 100 or more. They are approximate.

‡‡ Bricks are sold in any specified density between the two given. Length can be 8, 12 or 16 in.

§§ Other sizes available, and their weights: 2 × 10 × 4–19 lb, 2 × 12 × 4–22, 4 × 8 × 8–29, 6 × 10 × 4–56.

shapes or machined finished forms. Carboloy department of General Electric Co., 11130 East Mile St., Detroit, Mich., sells Hevimet, with a specific gravity of from 16.9–17.2. The half-value layer for Co^{60} is 0.330 in. Fansteel Metallurgical Corp., North Chicago, Ill., sells Fansteel "77." The specific gravity varies from 16.7–17.1. The alloy is approximately 1.5 times as effective as lead in radiation absorption. P. M. Mallory, 3029 East Washington St., Indianapolis 6, Ind., sells Mallory 1000 metal. Its specific gravity is 17. Half-value layer for Co^{60} is 0.295 in.

Reprints of this report, at 10 cents each, can be obtained from Reprint Department, NUCLEONICS, 330 West 42nd St., New York 36, N. Y.

BIBLIOGRAPHY

1. R. Stephenson, "Introduction to Nuclear Engineering" (McGraw-Hill Book Co., Inc., New York, 1954)
2. U. Fano, Gamma-ray attenuation, NUCLEONICS **11**, No. 8, 8 (1953)
3. G. R. White, NBS-1003, (National Bureau of Standards, U. S. Department of Commerce, Washington, D. C., 1952)
4. Handbook 54, "Protection Against Radiations from Radium, Co^{60} and Cs^{137}" (National Bureau of Standards, U. S. Department of Commerce, Washington, D. C., 1954)
5. J. Moteff, APEX-176, Miscellaneous Data for Shielding Calculations (1954)
6. M. Brucer, Marble as a radiation shield, NUCLEONICS **13**, No. 1, 65 (1955)
7. P. M. Frazier, *et al.*, AECU-2967, Radiation Safety in Industrial Radiography with Radioisotopes (1954)

Nuclear Exhibits at the IRE Show

Nuclear components and instruments were well represented at the 704-exhibit electronics show held in conjunction with the recent IRE convention. Here is an account of some of the exhibitors and their new products.

• Amperex Electronic Corp., 230 Duffy Ave., Hicksville, N. Y., had on display two 900-volt halogen-filled Geiger counters with 1.4-mg/cm² windows. Model 230N is ⅝ in. in diameter, 1½ in. long; model 240N has same diameter but is 6 in. long thus combining the features of end-window and gamma counters.

• Atomic Instrument Co., 84 Massachusetts Ave., Cambridge 39, Mass., showed its line of nuclear instruments. Their new model 312 200–1,400-volt high-voltage supply with 0.02%/day stability and 0.01% regulation for 100–130-volt line variation was shown as used with Atomic's new single-channel scintillation spectrometer. Atomic showed several Dekatron scaling circuits for industrial counting.

• Chatham Electronics, Corp., Livingston, N. J., has been making radiation-detecting equipment for the armed services for several years. At the IRE show they exhibited commercial products: a reversible (+ or −) friction charger for easy adjustment of pocket dosimeters, a condenser-chamber dosimeter that is easily read with an auxiliary reader, and a 0–0.003-mr/hr scintillation ratemeter for prospecting.

• Condenser Products Co., 140 Hamilton St., New Haven, Conn., showed self-contained, unregulated power supplies ranging from 2 kv, 2.5 milliamps, to 50 kv, 1.0 milliamps that can be used directly or as a building block for regulated high-voltage supplies.

• Daystrom Instruments Division, Daystrom, Inc., Archbald, Pa., displayed a complete reactor control panel including log *N* amplifiers, period amplifier, log-count-rate amplifier, sigma amplifier, and safety channels.

• Haydu Brothers, Plainfield, N. J., exhibited the Burroughs magnetron beam-switching tube whose 10-position scaling at rates beyond 1 mc suggests application to fast scaler stages.

• Laboratory for Electronics, 75 Pitts St., Boston 14, Mass., had preset decade counting units for frequencies up to 100 kc and a model 504 digital recorder that can print decade-scaler totals up to 60 times per minute.

• P. M. Lennard & Co., Inc., 312 Pine St., Jersey City, N. J., have adapted their dryboxes to permit induction welding in an inert atmosphere.

• Mullard Ltd., Century House, Shaftesbury Ave., London, W. C. 2, England, and their American representatives, International Electronics Corp., 81 Spring St., New York, N. Y., exhibited a full line of standardized halogen-quenched Geiger counters. This new line includes the all-metal 7-in.-long ⅞-in.-diameter MX120 with 400-volt operating voltage and the glass 3-in.-long 0.4-in-diameter MX119 that delivers 50 μamps per pulse into a 5.4-megohm load at 575-volt counter voltage. They also make a well-type Geiger counter, rectangular-faced cathode-ray tubes, and image-converters.

• Standard Piezo Co., Carlisle, Pa., had a new solid-state fall-out detector. A ¼ × ⅛ in. crystal of photoconductive cadmium sulfide causes simple d-c relay circuit to trip when radiation level exceeds 5 r/hr. More sensitive models are forthcoming.

• Tracerlab, Inc., 130 High St., Boston, Mass., exhibited a new version of the Cutie Pie, the SU-1H, which now includes a 150-mr integrating scale. Another Tracerlab development is a "five-peak analyzer," essentially a five-channel pulse-height analyzer whose channels need not be contiguous; this

Products Index

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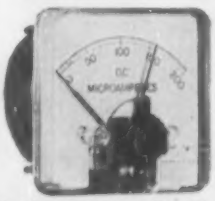

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The trip point is adjustable to any point on the scale arc.

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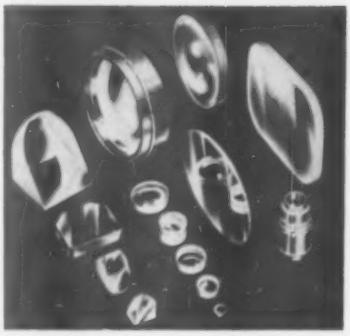
Three sizes of clear plastic case models, 2½, 3¾ and 4½ inches (all rectangular). Two ruggedized and sealed models, 2½ and 3½ inches (round metal cases). Contact arrangements: High Limit Single, Low Limit Single or Double (both high and low). Contact rating is 5 to 25 milliamperes D.C.

Suggested circuits for meter-relays and complete specifications including prices are covered in new 16-page Bulletin G-6, which you can get by writing Assembly Products, Inc., Chesterland 28, Ohio.

permits simultaneous counting of five scintillation-spectrum peaks.

• The Victoreen Instrument Co., 3800 Perkins Ave., Cleveland 14, Ohio, exhibited deep-hole scintillation probes with 200–5,000 feet of cable and recording accessories as new additions to their line of prospecting instruments.

LABORATORY INSTRUMENTS AND APPARATUS



Optical Equipment

Lenses, prisms, and optical subassemblies such as shown above are manufactured in large or small lots. Vacuum coating with Al, Ag, Au and MgF is available. Dichroic and Vignetted coatings are produced to specification.—Zenith Optical Laboratory, Copiague, N. Y.

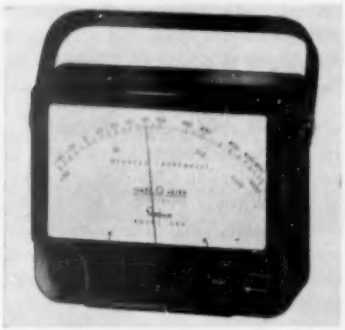
Inspection Device

Powered by flashlight batteries, Syte-Ayde provides four light-transmitting rods, 3½ and 6-in. long, straight and 90 deg bent (shown above). Three 1½-power mirrors come with this low-priced kit, can be clipped to rod ends.—General Scientific Equipment Co., 2700 W. Huntingdon St., Philadelphia 32, Pa.

Molecular Filter

Filtration rates of 250 ml/hr are attained with filter medium containing 10-mμ pores, supported so it withstands 100 psi. Ordinary pressure filtration techniques are used to oper-

ate the filter, which will separate large molecules from solutions. Filter can be reactivated by washing with water.—Emil Greiner Co., 20–26 N. Moore St., New York 13, N. Y.



Wide-Range Thermometer

Reading from −50–1,000° F on one 7-in. scale, the portable model 388 Therm-O-Meter (above) has a 7½-ft lead to a self-compensating thermocouple. Self-shielded meter movement eliminates interference. Model 388-3L has three leads, and switch to read any of three.—Simpson Electric Co., 5200 W. Kinzie St., Chicago 44, Ill.

Surface tensiometer. Model T-30 tensiometer needs only 0.02-ml sample to measure maximum pressure obtainable inside small bubble formed over an orifice. Sample and orifice are in a closed heating jacket.—National Instrument Laboratories Inc., 6108 Rhode Island Ave., Riverdale, Maryland.

Hot distilled water. With 1.5-gal capacity, heater keeps distilled water at predetermined temperature. Tank is of tinned copper and has removable cover. Dial thermometer to 240° F is included.—Barnstead Still and Sterilizer Co., 222 Lanesville Ter., Forest Hills, Boston 31, Mass.

Chain-loaded balance. With 1-kg capacity, the Reyers-Rapid balance has two chains, so raising balance does not upset equilibrium. Chain loading device is adjustable to 10 mg, the sensitivity of the balance.—Arthur S. LaPine & Co., 6001 S. Knox Ave., Chicago 29, Ill.

Moisture-content balance. Single beam and vernier slide weight combine on model DB-5 torsion balance to allow direct moisture-content measurements from 0.1–100% for 2, 5, or 10-gm samples. Two tares on slide wire, one for sample other for container, speed up measurements.—

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The Torsion Balance Co., Clifton, N. J.

Line of micropipettes. Pyrex glass micropipettes with capacities from 1 lambda (0.001 ml) to 1 ml are offered in many types. Special sizes and styles are available.—Research Specialties Co., 1148 Walnut St., Berkeley 7, Calif.

Ultrasonic drill. Surface finishes of 18–20 μin. and accuracy of 0.003 in. are claimed using a 50-watt ultrasonic drill, that produces a vertical reciprocating action. All normal machining operations can be done.—International Electronics Corp., 81 Spring St., New York 12, N. Y.

Ultrasonic drill. Portable U 600 ultrasonic drill weighs 15 lb, including generator, drills to tolerance of 0.0005 in. in hard materials like glass, tungsten carbide, sapphire, ceramics and hardened steel.—Vibro-Ceramics Corp., Metuchen, N. J.

Resistance thermometer elements. With −100–500° F range, SN-1 Stickon resistance thermometer elements are 0.010-in. thick. Resistance element is thin nickel wire, in glass fiber fabric. Units can be cemented to surfaces, have fast response.—Ruge-De Forest Inc., 50 Moulton St., Cambridge 38, Mass.

Light-scattering photometer. Operating on 115 v, 60-cycle current, Universal 1000 photometer can detect 12 μμlumens of blue light. It is portable and has outlet connections for recorders, galvonometers and servo-scale expanders.—Phoenix Precision Instrument Co., 3803-05 N. 5th St., Philadelphia 40, Pa.

INDUSTRY NOTES

▶**Minneapolis-Honeywell Regulator Co.**, Minneapolis, Minn. and **Raytheon Mfg. Co.**, Waltham, Mass., have formed a jointly-owned corporation, **Datamatic Corp.**, to engineer and market electronic data-processing systems.

▶**Panellit, Inc.**, Chicago, Ill., has acquired the **Jordan Electronic Mfg. Co.**, Pasadena, Calif., makers of radiation monitoring equipment. **Jordan** will be operated as a wholly owned subsidiary, and will adapt **Panellit's** alarm and scanning devices.

▶**Applied Research Laboratories**, Glendale, Calif., have completed

facilities for design and manufacture of X-ray and γ-ray optical elements and instruments. **Dr. J. W. M. DuMond** will be their consultant on design.

▶**Texas Instruments, Inc.,** Dallas, Tex., has purchased the **Radell Corp.,** Indianapolis, Ind., makers of deposited-carbon precision resistors. **Texas Instruments** manufactures electronic instruments and components.

LITERATURE AVAILABLE

Electronic instruments. Catalog 100 lists phase meters, amplifiers, impedance meters, oscillators, computers and services. 56 p.—Technology Instrument Co., Acton, Mass.

Nuclear services. New brochure describes personnel, facilities, and consulting, design, and research services of this new organization. 24 p.—Nuclear Science and Engineering Corp., Box 10901, Pittsburgh 36, Pa.

Radiation instruments. Geiger and scintillation counters and accessories for them are cataloged here. 12 p.—Precision Radiation Instruments, Inc., 2235 S. La Brea Ave., Los Angeles, Calif.

Millipore filters. Booklet provides latest technical and availability information on submicron-pore filters used in monitoring radioactive dusts. 38 p.—Millipore Filter Corp., Watertown 72, Mass.

Vibrating-reed electrometer. Bulletin describes model 30 electrometer that measures as low as 10^{-17} amp, 10^{-16} coulomb, and 0.02 mv. Also available is 16-page catalog that describes recording spectrophotometers for uv, visible, and infrared.—Applied Physics Corp., 362 W. Colorado St., Pasadena, Calif.

Film badges. Bulletin lists gamma, beta, and neutron film-badge services.—Radiation Detection Co., 576 College Ave., Palo Alto, Calif.

Nuclear instruments. Monthly brochure on nuclear instrumentation is inaugurated with discussion of DA5 linear amplifier.—Detectolab, Inc., 6544 N. Sheridan Rd., Chicago 26, Ill.

Automatic X vs Y Plotter. Data sheet E-ND46(1) describes automatic recorder for plotting X vs Y. 2 p.—Leeds and Northrup Co., 4934 Stenton Ave., Philadelphia 44, Pa.

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Radioisotope diagnostic manual. Procedures for using tracers in medical work are detailed. 30p.—Abbot Laboratories, North Chicago, Ill.

The Nucleus. Latest edition of this house organ features new analytical count-rate meter.—Nuclear Chicago, 229 W. Erie St., Chicago 10, Ill.

Titanium tubing. New bulletin lists properties, fabrication methods, and uses. 8p.—Superior Tube Co., 1552 Germantown Pike, Norristown, Pa.

Stainless valves. Bellows-seal, diaphragm-seal, O-ring-seal, and conventional-packing valves in ⅛–2-in. sizes are described.—Associated Valve and Engineering Co., 1150 W. Marquette Rd., Chicago 21, Ill.

Power supplies. Sixty-four variations of single and dual supplies are offered in "A Sensible Approach to Regulated Power Supply Design." 8p.—New Jersey Electronics Corp., 345 Carnegie Ave., Kenilworth, N. J.

Mass spectrometer. New brochure describes type 21-103C spectrometer. 16p.—Consolidated Engineering Corp., 300 N. Sierra Madre Villa, Pasadena 15, Cali".

Liquid-level gages. Bulletin 1161 describes schemes for measuring and controlling liquid level including by gamma rays.—Minneapolis-Honeywell Regulator Co., Wayne and Windrim Aves., Philadelphia 44, Pa.

X-ray diffractometer. Catalog CH 322/3 describes Hilger & Watts instrument that uses Geiger-counter detector.—Jarrel-Ash Co., 26 Farwell St., Newtonville, Mass.

Stainless filters. Bulletin 213 describes Surfmax filters for gases and liquids at pressures to 10,000 lb/in². 4p.—Micro Metallic Corp., 30 Sea Cliff Ave., Glen Cove, N. Y.

Colloidal graphite. Bulletin 433 describes use of colloidal graphite for electronic and Geiger tubes. 4p.—Acheson Colloids Co., Port Huron, Mich.

Electronic timers. Delay, repeat-cycle, and interval timers are included in the standard line described. 5p.—G. C. Wilson & Co., 1950 Eighth Ave., Huntington, W. Va.

Pt-clad tungsten. Non-sag platinum-clad tungsten wire developed for electronics industry is described.—Baker, 113 Astor St., Newark 5, N. J.

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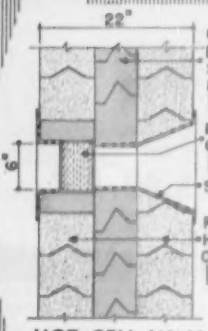

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LETTERS

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DEAR SIR:

We have been criticized severely concerning the omission of proper references and sources of information in the article "Reprocessing Reactor Fuels," by H. A. Ohlgren, J. G. Lewis, and M. E. Weech (NU, Mar. '55, p. 18).

We desire to acknowledge the basic development performed by Argonne National Laboratory in the field of bromine trifluoride volatility processing. Organizations which have made significant contributions to the field of pyrometallurgical processing are Ames Laboratory, North American Aviation, Inc., Argonne National Laboratory, and Brookhaven National Laboratory. Credit for the development of aqueous chemical processing belongs to Oak Ridge National Laboratory, Knolls Atomic Power Laboratory, Argonne National Laboratory, and General Electric Company, Hanford Works.

We are attaching a list of 44 references that were used as source material for our work.

1. "Approved Equipment for Industrial Fire Protection" (Associated Factory Mutual Fire Insurance Companies, 1949)
2. Manson Benedict. The chemical engineering side of nuclear power, American Chemical Society, Chicago (1953)
3. L. Brewer, L. A. Bromley, P. W. Gilles, N. L. Lofgren. Thermodynamic properties of uranium halides, oxides, nitrides, and carbides, NDDC-1543
4. F. R. Bruce. Chemical development of radiochemical processes, American Chemical Society, Auburn, Ala. (1952)
5. Cowan. Salicylate extraction of thorium from rare earths, AECD-3108 (1951)
6. D. Decroly, J. Van Impe. Critical study of methods of preparation of metallic uranium, *Bull. tech. A. I. Br.* **3**, No. 5 (1950)
7. "Educational Film Guide" (H. W. Wilson Co., New York, 1953)
8. C. Eichner, B. Goldschmidt, P. Vertes, *Bull. soc. chim. France* No. 5, 18, 140 (1951)
9. N. H. Furman, R. J. Mundy, G. H. Morrison. Distribution of uranyl nitrate from aqueous to di-ethyl ether, AECD-2938
10. General Electric Co., "Pump Mix Mixer-Settler," U. S. Patent 264,346
11. S. Glasstone, M. C. Edlund, "Nuclear Reactor Theory" (D. Van Nostrand Co., New York, 1952)
12. Griffith, Jasney, Tupper, M. S. thesis, Massachusetts Institute of Technology (1952)
13. F. Hecht, A. Grunwald, *Mikrochemie ver. Mikrochim. Acta* **30**, 279 (1943)
14. C. James, J. F. Groggins, J. J. Cronin, H. C. Fogg, *Ind. Eng. Chem.* **18**, 114 (1926)
15. J. J. Katz, E. Rubinowich, "The Chemistry of Uranium," National Nuclear Energy Series VIII-5 (McGraw-Hill Book Co., Inc., New York, 1951)
16. S. I. Levy, "The Rare Earths" (Arnold, London, 1924)
17. W. C. Liliendahl, J. E. Gray, H. C. Rentschler, "Production of Thorium Metal," U. S. Patent 2,446,062 (1948)
18. Martel, Calvin. "Chemistry of Metal Chelate Compounds" (Prentice-Hall, Inc., New York, 1952)
19. Bernard Manowits. The industrial future of radiation chemistry, NUCLEONICS **11**, No. 10, 18 (1953)
20. J. W. Marden, U. S. Patents 1,437,984, 1,646,734 (1927), 1,814,721 (1931), 1,602,542
21. W. W. Meinke. Chemical procedures used in bombardment work at Berkeley, AECD-2738 (1949)
22. W. W. Meinke. Addendum no. 1, AECD-2750 (1949)
23. W. W. Meinke. Addendum no. 2, AECD-3084 (1951)
24. Michigan State Police, Fire Bureau, Flammable Liquids Regulations, effective March 30, 1942
25. F. T. Miles, I. Kaplan. Optimizing and comparing reactor designs, *Chem. Eng. Progr. Symposium Series* **50**, No. 11, 159 (1954)
26. National Board of Fire Underwriters, Bulletin 54
27. A. Norstrom, L. G. Sillen, *Svensk Kem. Tidskr.* **60**, 227 (1948)
28. R. D. Parks, "Source Material for Nuclear Power in Science and Engineering of Nuclear Power" (Addison-Wesley Press, Cambridge, 1949)
29. E. Peligot, *Ann. chim. phys.* **351**, 1842
30. Laurence L. Quill, "The Chemistry and Metallurgy of Miscellaneous Materials," NNES-IV-19B (McGraw-Hill Book Co., Inc., New York, 1950)
31. V. L. Saine, K. D. Brown. Study of recovery processes of western ores, AECD-3241 (1949)
32. G. T. Seaborg, J. J. Katz, "The Actinide Elements" (McGraw-Hill Book Co., Inc., New York, 1954)
33. G. T. Seaborg, J. J. Katz, W. M. Manning, "The Transuranium Elements," National Nuclear Energy Series IV-14B, Parts 1 and 2 (McGraw-Hill Book Co., Inc., New York, 1949)
34. G. Sege, F. W. Woodfield, *Chem. Eng. Progr. Symposium Series* No. 13, 50, 179 (1954)
35. Selected values of chemical thermodynamic properties, NBS-500 (1952)
36. L. Stein, R. C. Vogel. Refractive indices of the systems uranium hexafluoride-bromine trifluoride and uranium hexafluoride-bromine pentafluoride, ANL-5051 (1953)
37. R. Stephenson, "Introduction to Nuclear Engineering" (McGraw-Hill Book Co., Inc., New York, 1954)
38. J. V. Nehemias, R. C. Dennis, Eugene Ambo. Calculated distribution of fission product nuclides, University of Michigan Report 2240-3-F (1954)
39. J. G. Lewis, R. J. Annesser, R. J. Hennig, M. E. Weech. Report of a literature survey of high temperature metallurgical refining processing, University of Michigan Report 2300-3-T (1954)
40. "Major Activities in the Atomic Energy Programs," U. S. Atomic Energy Commission (U. S. Government Printing Office, Washington, D. C., 1954)
41. "Reports to Nuclear Power Reactor Technology," U. S. Atomic Energy Commission (U. S. Government Printing Office, Washington, D. C., 1953)
42. W. J. D. Van Dijck, U. S. Patent 2,011,186 (1935)
43. A. M. Weinberg. Power reactors, *Sci. American* **191**, 33 (1954)
44. W. H. Zinn, NUCLEONICS, **10**, No. 9, 8 (1952)

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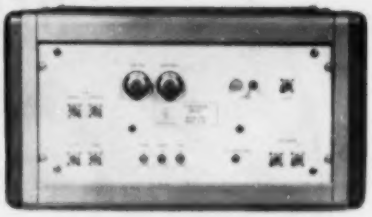

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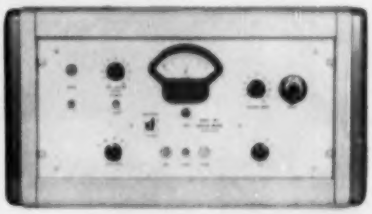

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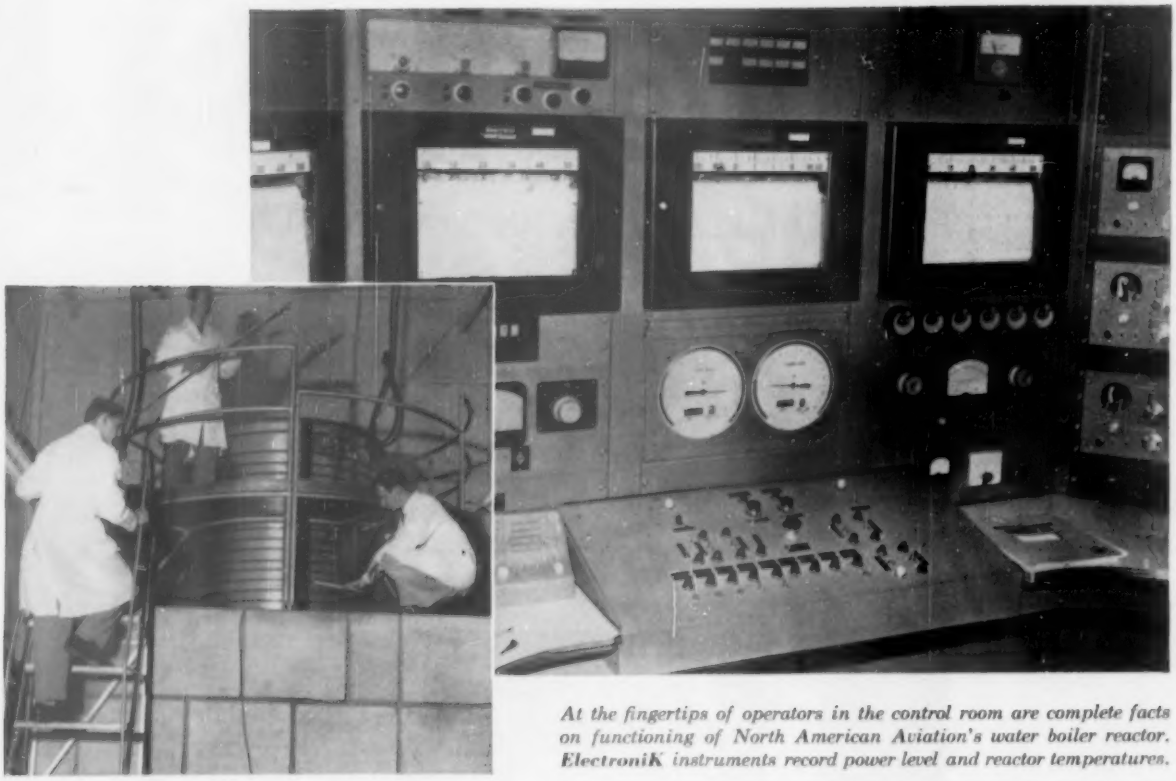

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